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VOLUME II

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McDonnell Aircraft Company
McDonnell Douglas Corporation
P.O. Box 516
St. Louis, Missouri 63166

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Aero Propulsion Laboratory
Air Force Wright Aeronautical Laboratories
Air Force Systems Command
Wright-Patterson Air Force Base, Ohio 45433

NOTICE

This technical report has been reviewed and is approved for publication.

Emil D. Blevins

Erich Bailey

FOR THE COMMANDER

James M. Shipman

JAMES M. SHIPMAN, Major, USAF
Deputy Director
Turbine Engine Division

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J. G. Osmer
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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)
In early gas turbine engine conceptual design, a complex interactive aircraft/engine design effort is conducted. The primary objective of the Life and Utilization Criteria Identification in Design (LUCID) Program was to develop and demonstrate techniques which will aid in identifying, during conceptual design, balanced and consistent performance and life capability goals with which to proceed to engineering development.

In Volume I, a methodology for quantifying relative life/performance trades during the conceptual design phase of gas turbine engine development is presented. As part of this methodology, a computer-aided design system employing regression techniques has been developed and demonstrated. Major elements of this system are performing satisfactorily. However, certain component subroutines are exhibiting unacceptable error levels. Further effort is required in this innovative application of regression techniques.

In Volume II, procedures to predict engine usage are presented. Peacetime missions were defined for an advanced tactical strike aircraft and were employed by the usage models to generate a composite engine duty cycle. The engine duty cycle was analyzed and compared to engine usage projections for other advanced tactical aircraft. The analysis demonstrated significant variations in engine variations in engine usage due to weapon delivery tactics associated with advanced air-to-surface missiles, as well as variations in peacetime mission frequencies and aircraft performance.

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SUMMARY

Peacetime usage is an important consideration in design of advanced fighter engines. Engine duty cycles are affected by many factors including the maneuvers performed in pilot training missions, the performance capabilities of the aircraft, and pilot tactics. In the "Life and Utilization Criteria Identification in Design" (LUCID) study funded by AFAPL (Contract F33615-78-C-2032), procedures were developed to predict engine duty cycles. The engine usage analysis was conducted by MCAIR under a subcontract with P&WA (P.O. 140390).

In the development of usage prediction procedures, MCAIR digital flight simulation models were modified to compute throttle time histories for peacetime mission segments. With these models, aircraft performance and training mission variations can be reflected in advanced engine duty cycles.

Peacetime missions were defined for an advanced tactical strike aircraft by reviewing training missions flown by current attack aircraft and projecting training requirements for advanced weapon systems. The flight profiles and training maneuvers were input, along with aircraft performance data, into the usage models. Altitude, airspeed and throttle time histories were computed for each mission. The throttle time histories were analyzed to determine the throttle cycle and hot time accumulations per mission and a composite engine duty cycle was computed using the mission frequency weightings. The results were analyzed and compared to engine usage projections for other advanced tactical strike configurations.

The analysis demonstrated significant variations in engine usage due to weapon delivery tactics associated with advanced air-to-surface missiles, as well as variations in peacetime mission frequencies and aircraft performance.

1. INTRODUCTION

Systematic procedures to project duty cycles for advanced fighter engines have not been available in the past. Such procedures are needed to reflect the influences of advanced weapon system capabilities on engine usage. Realistic duty cycles will enable engine design studies to properly establish the balance between life, performance and cost in advanced fighter engines. MCAIR has initiated the development and verification of such a procedure as a subcontractor to Pratt & Whitney Aircraft Group Government Products Division in the USAF-sponsored "Life and Utilization Criteria Identification in Design" (LUCID) program.

Duty cycles have previously been derived from combat mission requirements or from historical data. These approaches do not adequately define the engine usage which may be encountered in advanced fighters. Engines such as the TF41 and F100 have encountered durability deficiencies and greater operating and support costs than expected because actual peacetime usage is more severe than design duty cycle projections.

An investigation of A-7/TF41 operational usage, Reference 1, indicated that engine usage in peacetime training is significantly different than combat usage. Combat missions contain substantial periods of high power, high speed operation but few throttle transients. In peacetime missions, both throttle cycle and hot time accumulations are high due to the repeated training events occurring in these missions. Therefore, the low cycle fatigue damage in peacetime missions is much more severe than in combat missions. Engine duty cycle projections must consider peacetime operation.

Similarly, the F100 design duty cycle did not reflect engine usage rates currently being accumulated in F-15 training missions. Actual engine usage rates exceed the design duty cycle by 42% for throttle cycles and 334% for afterburner cycles. However, hot time accumulations are 61% less than predicted. Throttle cycle accumulation rates in F-15 air combat training are higher than for past fighters due to its increased thrust-to-weight. Engine duty cycles must consider aircraft performance effects.

This report describes the technical approach selected for projecting engine duty cycles and reviews the analytical models and peacetime mission analysis used in the procedure.

Initial applications of the new procedure have shown that engine usage is highly sensitive to variations in training missions and weapon delivery tactics due to advanced weapon systems. Usage is also shown to be sensitive to changes in peacetime mission frequencies and variations in aircraft performance capabilities. Further analysis is needed to identify important usage parameters and to quantify the effects of parameter variations on engine duty cycles. The analytical procedures are now available to conduct these investigations.

2. TECHNICAL APPROACH

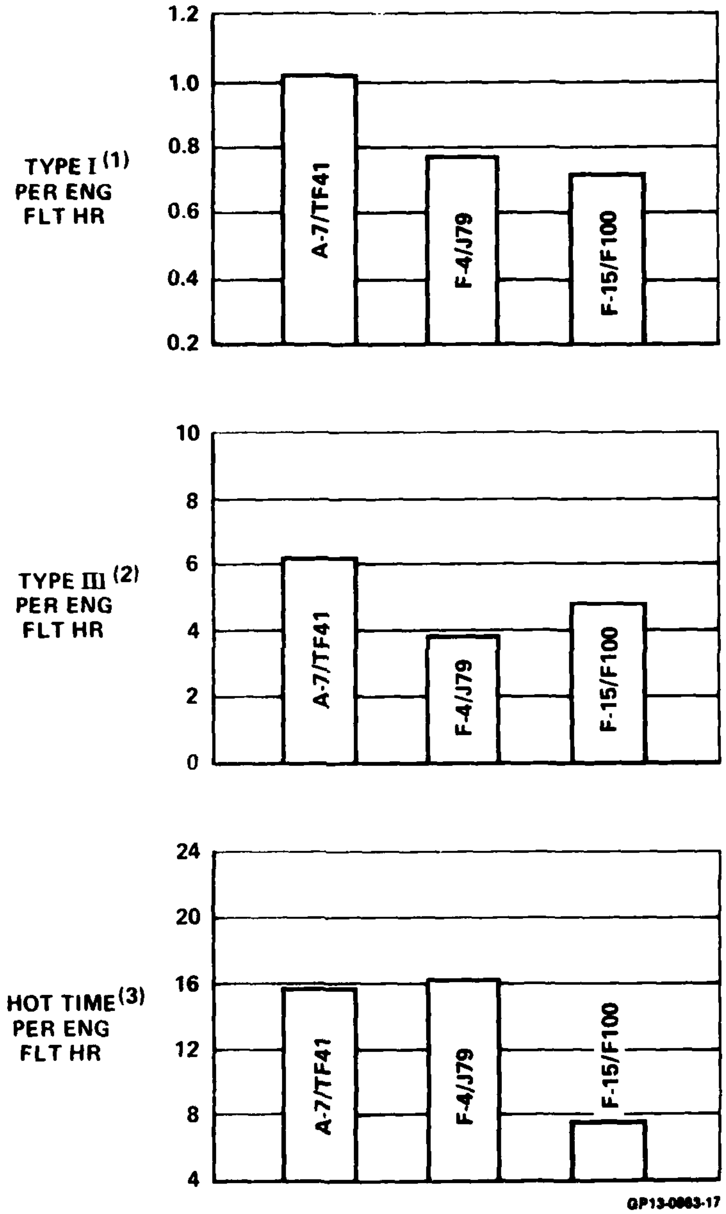
Significant differences exist in engine usage rates for fighter aircraft. A consistent data base to quantify and predict these differences is not available. However, engine usage data for the F-15/F100, F-4/J79, and A-7/TF41, are presented in Figure 1 based on events history recorder data (F-15/F100) and pilot interviews (F-4/J79 and A-7/TF41). It can be seen that differences in combat roles and aircraft performance levels are reflected in the engine usage results.

The usage prediction procedure developed in LUCID was designed specifically to enable engine duty cycle projections which reflect changes in peacetime missions, combat tactics, and aircraft performance. The procedure is shown in Figure 2. It uses digital flight simulation models to compute throttle time histories for peacetime missions. Mission segments simulated in the models include takeoffs, climbs, descents, cruises, aerial refueling, accelerations, decelerations, terrain following, air combat training, ground attacks, and landings. The inputs required by the usage models include (1) descriptions of the mission segments and training maneuvers from takeoff to landing for each peacetime mission and (2) the aircraft performance characteristics throughout the flight envelope. Variations in missions, combat tactics and aircraft performance can be accomplished through changes to these inputs.

The throttle time histories are analyzed to determine the throttle cycle and hot time accumulation rates for each mission and an engine duty cycle is computed by applying the frequency weighting. The duty cycles are provided to engine companies for engine life assessments.

The usage prediction methodology was validated in MCAIR IRAD studies, References 2 and 3. Engine usage was predicted for the F-15/ F100 at three Air Force bases at which the F-15 is currently deployed. The bases were Bitburg AFB and Eglin AFB, which are operational bases, and Luke AFB, a transitional training base. The usage predicted using the LUCID procedures was compared to actual engine data for these bases. Throttle cycle and hot time accumulations were recorded by F100 Events History Recorders (EHR). The results, shown in Figure 3, indicate good agreement between predicted and actual engine usage. Further efforts are required to validate and update the usage prediction procedures and mission data base and to assess the predictions on a mission segment-by-segment basis. These assessments are necessary to ensure that the impact of engine and airframe variations and advanced weapons, fire control, and combat tactics are properly represented.

FIGURE 1
CURRENT AIRCRAFT USAGE DATA



Notes:

(1) Type I = engine off to intermediate to off

(2) Type III = idle to intermediate to idle

(3) Hot time = minutes at intermediate power or greater

FIGURE 2
USAGE PREDICTION PROCEDURE

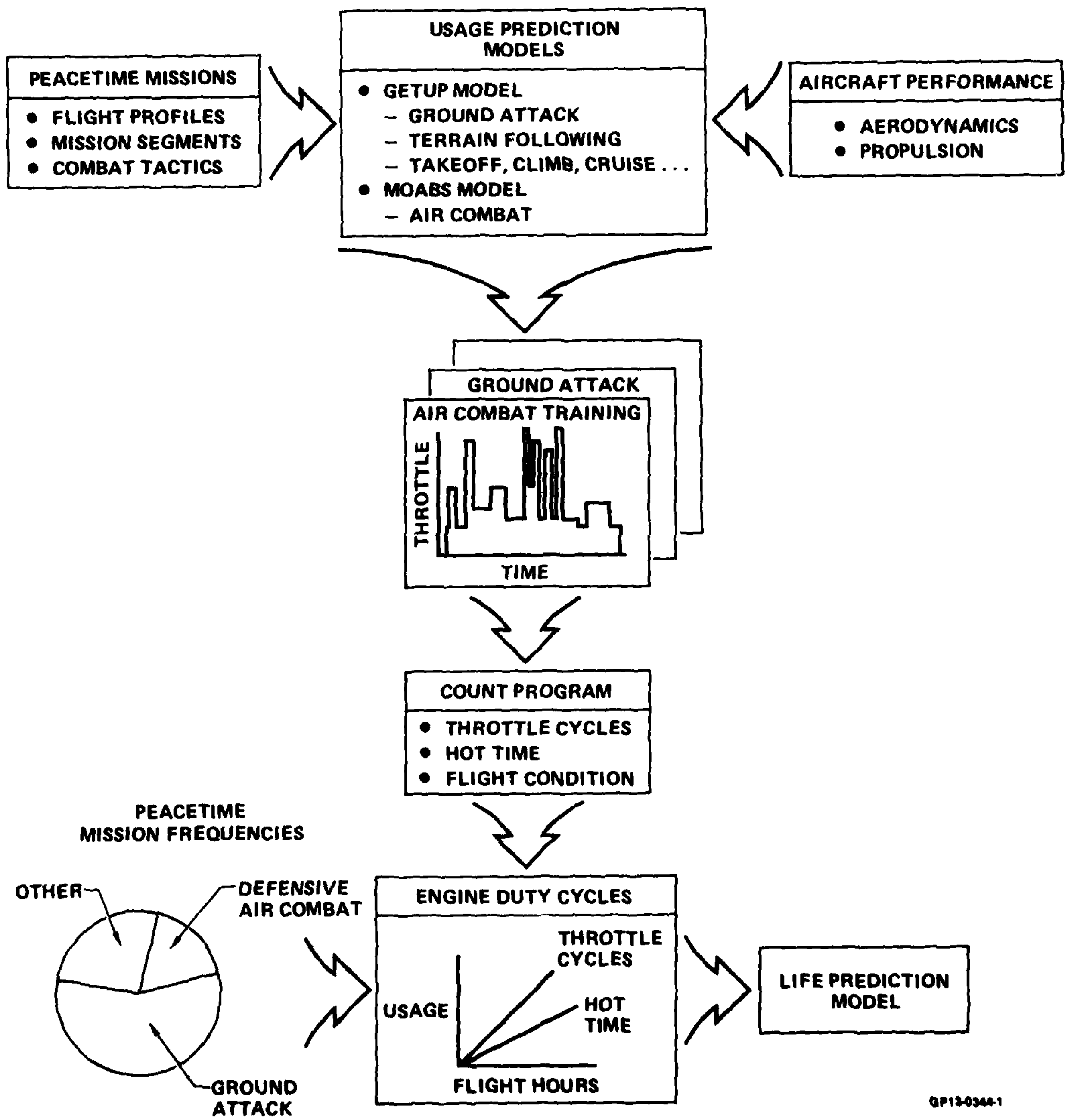


FIGURE 3
USAGE MODEL VALIDATION

ENGINE DUTY CYCLE[1] (2,000 ENGINE RUN HOURS)	AIR FORCE BASES		
	BITBURG	LUKE	EGLIN
TYPE I CYCLES			
• ACTUAL	878	920	1,004
• LUCID PREDICTION	952 (8.4%)	965 (5.0%)	1,036 (3.2%)
TYPE III CYCLES			
• ACTUAL	6,318	7,162	6,462
• LUCID PREDICTION	6,568 (4.0%)	7,668 (7.1%)	6,493 (0.5%)
HOT TIME (HR)			
• ACTUAL	184.0	208.9	213.5
• LUCID PREDICTION	–	209.7 (0.4%)	202.5 (–5.2%)

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[1]Duty cycle used in F100 design (2,000 engine run hours)
Type I cycles 1,765
Type III cycles 0
Hot Time . . . . 525 hr

3. ENGINE USAGE PREDICTION MODELS

Two existing flight simulation models were modified in LUCID to compute throttle time histories in the flight segments of peacetime missions. Air combat training is simulated using the MCAIR Multiple Opponent Air Battle Simulator (MOABS) and all other mission segments are simulated in the Generalized Engine Throttle Usage Prediction (GETUP) model.

Engine operations on the ground including pre- and post-flight warm-ups, system checks, engine maintenance and diagnostic operations were analyzed as well as flight segments. Ground operations for advanced engines were represented by reviewing data for current fighter engines and projecting the effects of advanced engine and aircraft technologies on ground operations.

A computer program, COUNT, was developed to analyze the throttle time histories and determine the throttle cycle and hot time accumulations for each mission. The usage models and the cycle counting program are described below.

3.1 GENERALIZED ENGINE THROTTLE USAGE PREDICTION (GETUP) MODEL - The GETUP model was evolved from the MCAIR Dive And Release Trajectory (DART) model. DART was originally developed to compute time-dependent ground attack trajectories for input into survivability models. Usage prediction capability was added to DART by developing the logic necessary to compute throttle time histories along with flight path trajectories. In addition, the set of predefined maneuvers that can be simulated was expanded to include training mission segments. The maneuvers simulated in the DART model were limited primarily to ground attack weapon deliveries.

The mission segments simulated in the usage models include: takeoff, climb, cruise, air combat training, ground attack training, aerial refueling, terrain following, descent, and landing. Predefined maneuvers such as Split-S, pitch-backs, sustained turns, and oblique loops are also simulated.

Aircraft flight is simulated in GETUP using three degree-of-freedom equations of motion. The flight parameter inputs required to describe a mission segment include initial and final flight conditions, and the maneuvers and maneuver constraints. The initial conditions include altitude, airspeed, heading, aircraft weight, pitch angle and normal load factor. The final conditions are altitude, airspeed and heading. The maneuver constraints include load factor limits, climb angle limits and power setting limits (i.e. augmented or dry power). The distance over which the maneuver is to be completed is also specified.

Aircraft performance inputs include aerodynamic characteristics (e.g. drag polars, C_L vs. α, roll rates, etc.) and propulsion characteristics (net propulsive force and fuel flow at selected power settings) throughout the flight envelope. The maneuver and aircraft performance inputs are summarized in Figure 4.

The standard output provides the following time history data: throttle positions (PLA in degrees), velocity (knots, Mach number or feet per second), altitude (feet Mean Sea Level), range (nautical miles), azimuth heading (degrees), flight path angle (degrees), roll angle (degrees), normal load factor (g's), speed brake position, and fuel usage (pounds).

The steering logic in the program is essentially a vector resolution of the current velocity vector of the aircraft and the velocity vector required to reach the desired final conditions and complete the maneuver. Normal and tangential acceleration requirements are determined from the velocity vector resolution and aerodynamic and propulsion forces needed to generate these accelerations are computed. These forces determine the aircraft orientation (bank angle and pitch angle) and the power settings for a specified time step. The equations of motion are integrated, and incremental changes to the flight trajectory are computed for the selected time step. When the desired end conditions are achieved, the maneuver is terminated.

The maneuvers developed for the GETUP model provide the capability to simulate a broad range of peacetime mission segments. Examples are illustrated in Figure 5. Flight test data and pilot descriptions of training maneuvers have been used to develop the predefined maneuvers simulated in the GETUP model.

Takeoff and landing options include conventional, short and vertical takeoffs and landings. In addition, overhead, straight-in, and touch and go landing patterns are simulated. Climbs can be conducted at the maximum climb rate of the aircraft or at a specified climb angle.

The terrain following routine simulates aircraft flight over an input terrain profile. The simulation is based on the F-111 radar algorithm, Reference 4. The additional terrain following inputs are the range of the radar, ground clearance, airspeed, and ride setting (hard, medium, and soft). Figure 6 illustrates the terrain following simulation for a high thrust-to-weight (.7) and a low thrust-to-weight (.3) aircraft. A sample terrain profile representing Central European terrain was selected for this example. The throttle time history variations for the two aircraft illustrate the capability of the GETUP model to predict the effects of changes in aircraft performance on engine usage.

FIGURE 4
GETUP MODEL INPUTS/OUTPUTS

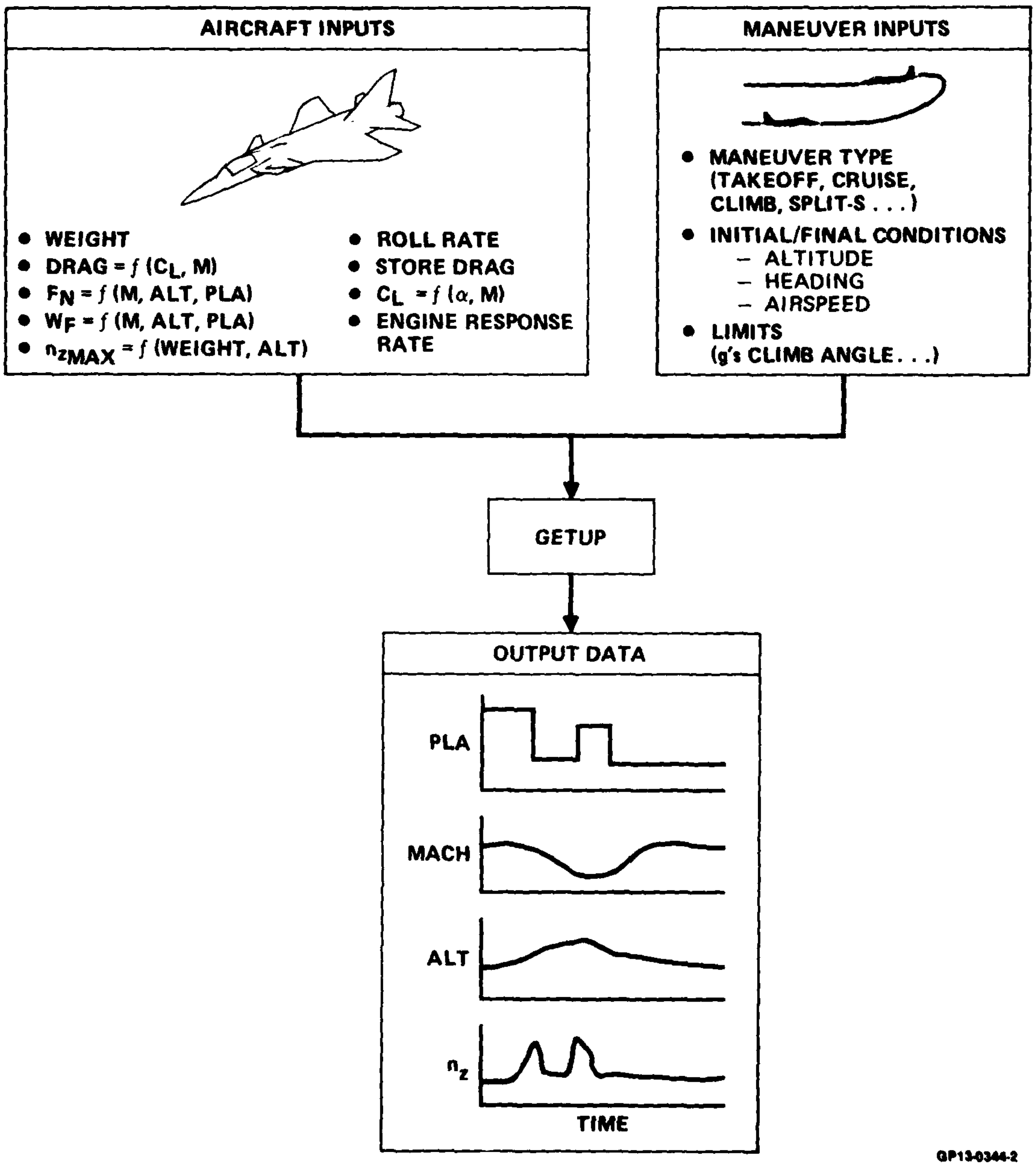


FIGURE 5
MANEUVERS SIMULATED IN GETUP

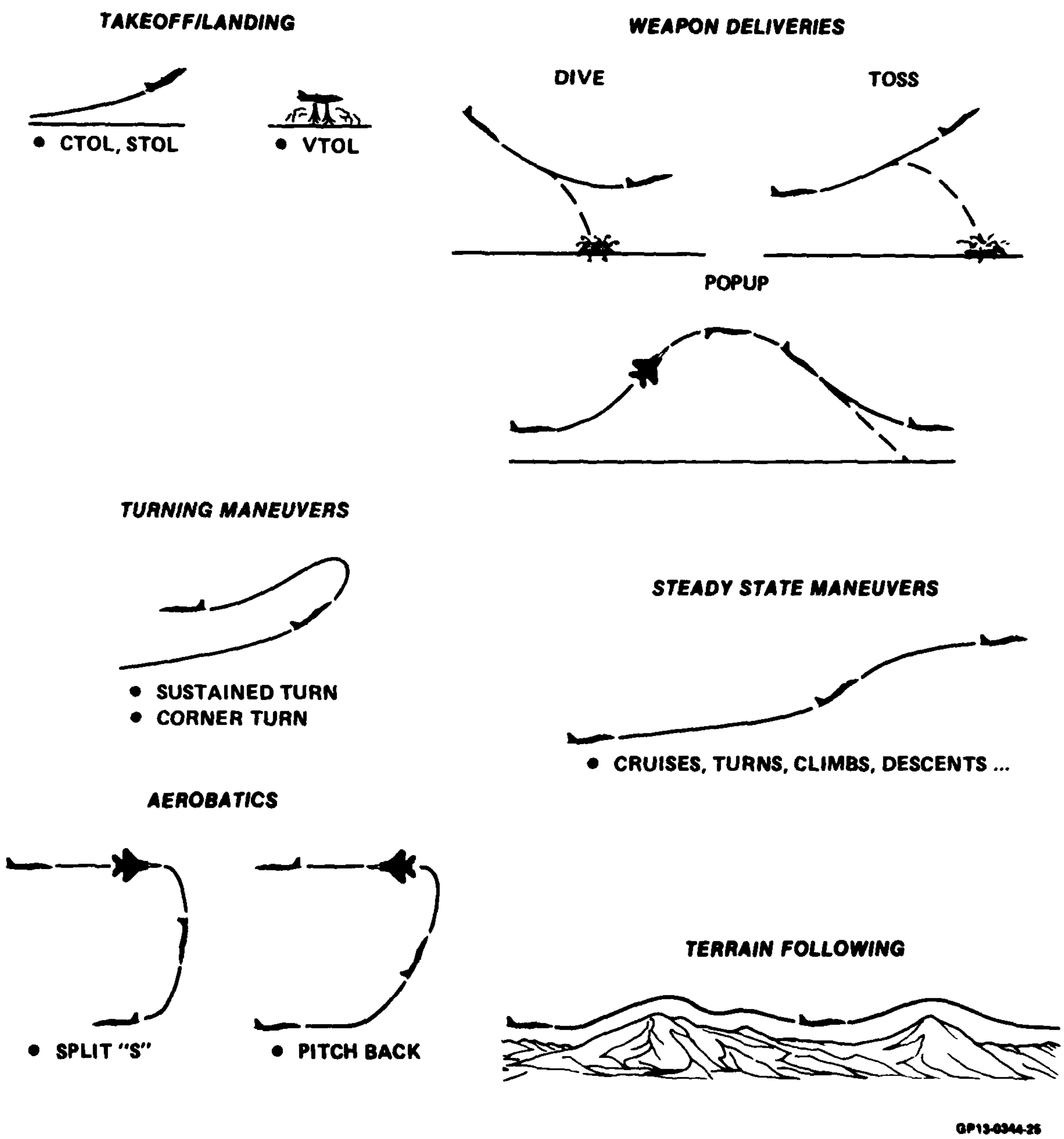
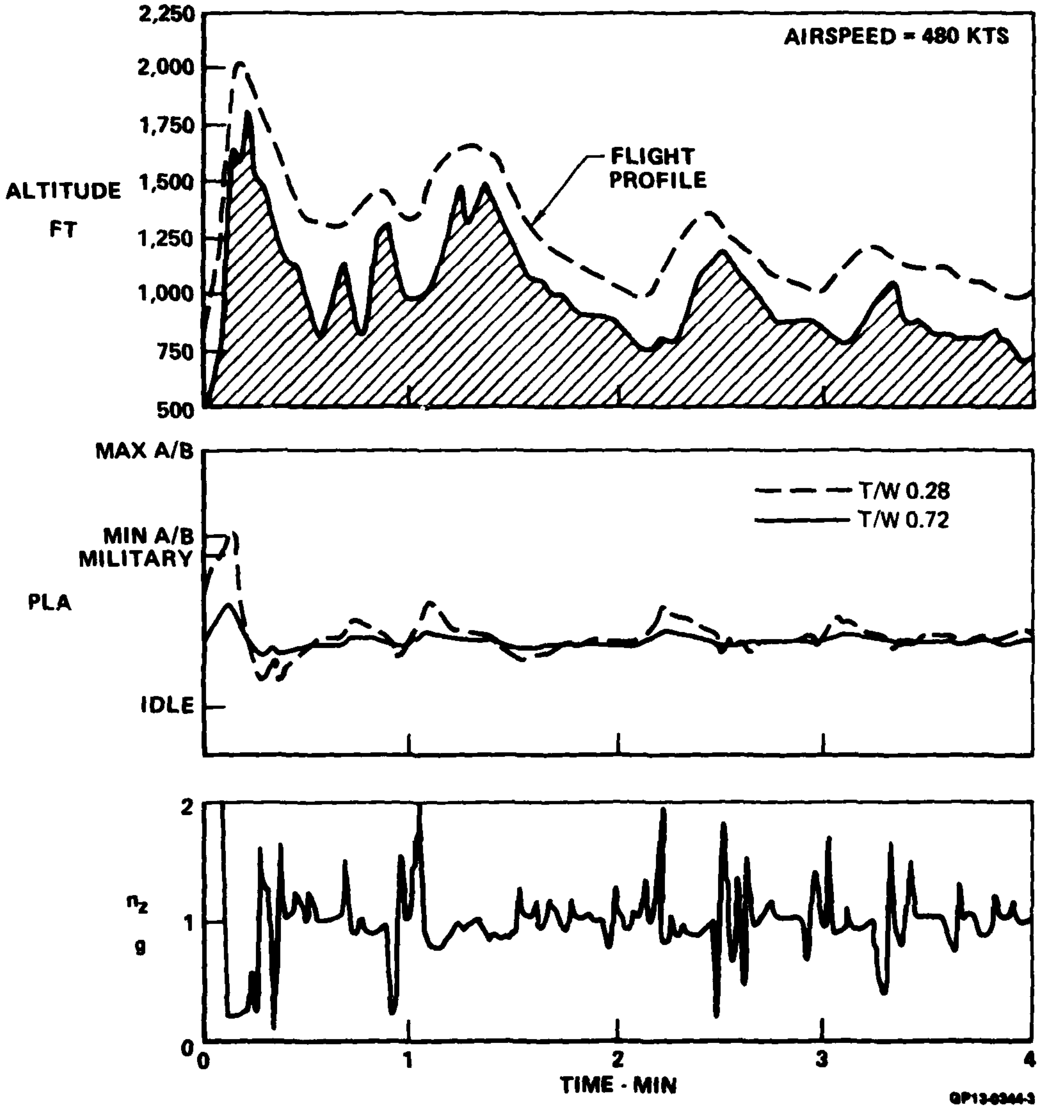


FIGURE 6
TERRAIN FOLLOWING SIMULATION



Aerial refueling is simulated through the use of a rejoin maneuver. The position, heading and airspeed of the tanker are input along with the distance over which the rejoin is to be accomplished. A fuel transfer can also be simulated. The rejoin maneuver is also used in simulating formation maneuvers.

Ground attack maneuvers which are simulated include low altitude weapon deliveries such as pop-ups, dive bombs, tosses and strafing and high altitude, supersonic weapon deliveries with advanced air-to-surface missiles. The pop-up routine determines the flight path trajectory and the weapons release point for specified target positions and flight path constraints (e.g. g-limits, climb angles, dive angles and airspeeds).

Aerobatic maneuvers performed in pilot familiarization training can be simulated in GETUP, including Split-S's, pitch-backs, sustained turns, and others. The Split-S simulation is illustrated in Figure 7.

The maneuvers described above can be analyzed independently or in a sequence of maneuvers representing an entire mission. Figure 8 shows a mission time history computed for a ground attack training mission. The throttle time histories computed by the GETUP model are analyzed to determine the throttle cycle and hot time accumulations for each mission.

3.2 MULTIPLE OPPONENT AIR BATTLE SIMULATOR (MOABS) - Air combat training is simulated in the MOABS model. The equations of motion used in MOABS are identical to those in GETUP. However, flight maneuvers are not predefined, but are deterministically computed based on established air combat tactics programmed into the model. These tactics consider factors such as aircraft performance and weapons capabilities, threat performance and weapons, force ratios (e.g. 1V1, 1V2, 2V4, etc.) and positional advantage. Throttle usage is computed in MOABS for a specified set of starting conditions and aircraft performance characteristics. Figure 9 illustrates the procedure for computing usage during air combat mission segments.

The takeoff, landing, and cruise segments of the air combat training missions are simulated in GETUP and combined with the air combat training segments from MOABS to form a complete mission. This procedure is shown in Figure 10.

3.3 GROUND OPERATIONS SIMULATION - Representations of engine usage in pre- and post-flight ground operation and during engine maintenance and diagnostics are required to compute an engine duty cycle. The simulation of pre- and post-flight operation for advanced fighters was developed by reviewing data for current aircraft and projecting advanced systems impacts on these operations.

FIGURE 7
SPLIT-S SIMULATION

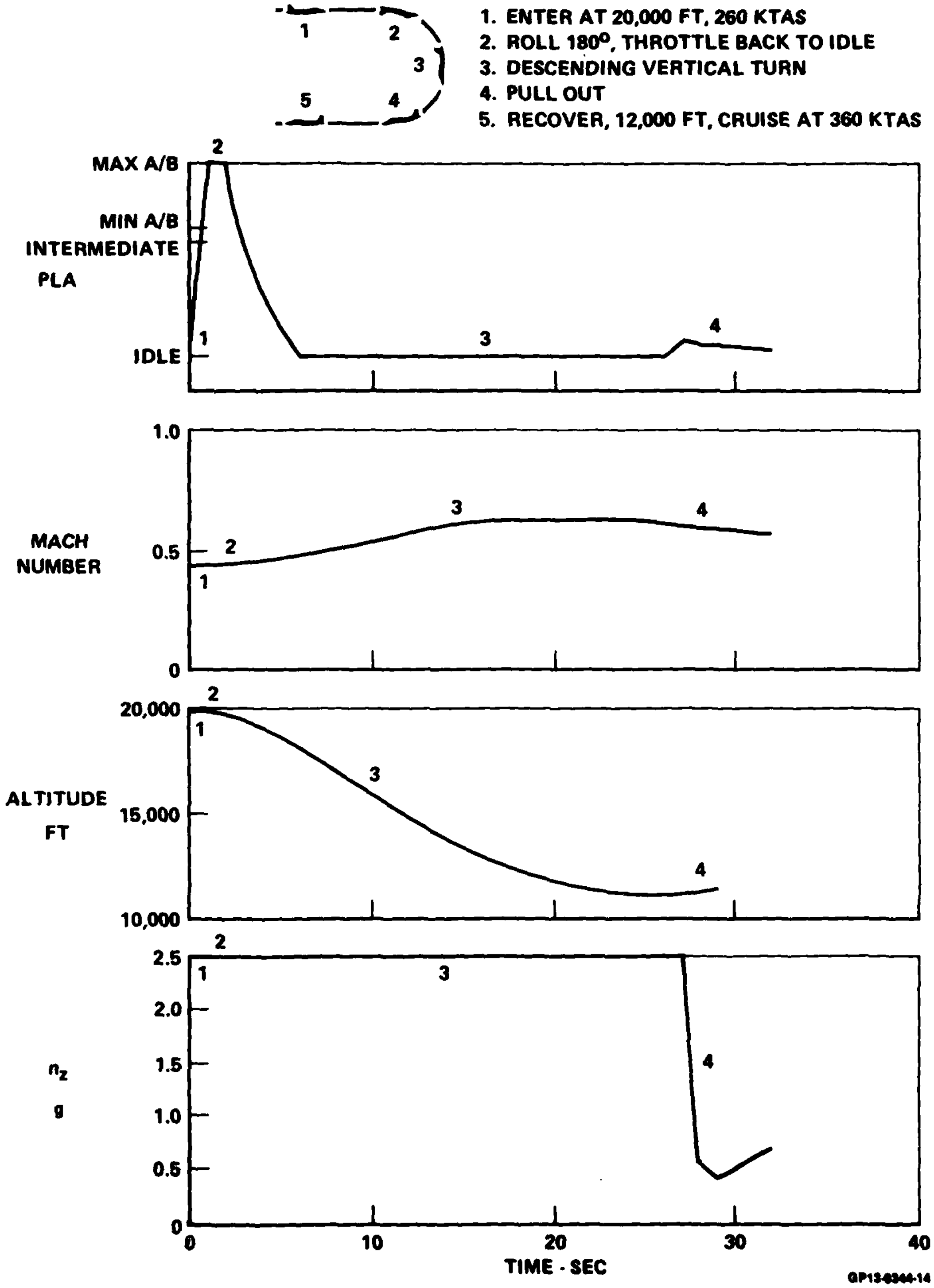


FIGURE 8
LOW ALTITUDE GROUND ATTACK TRAINING MISSION

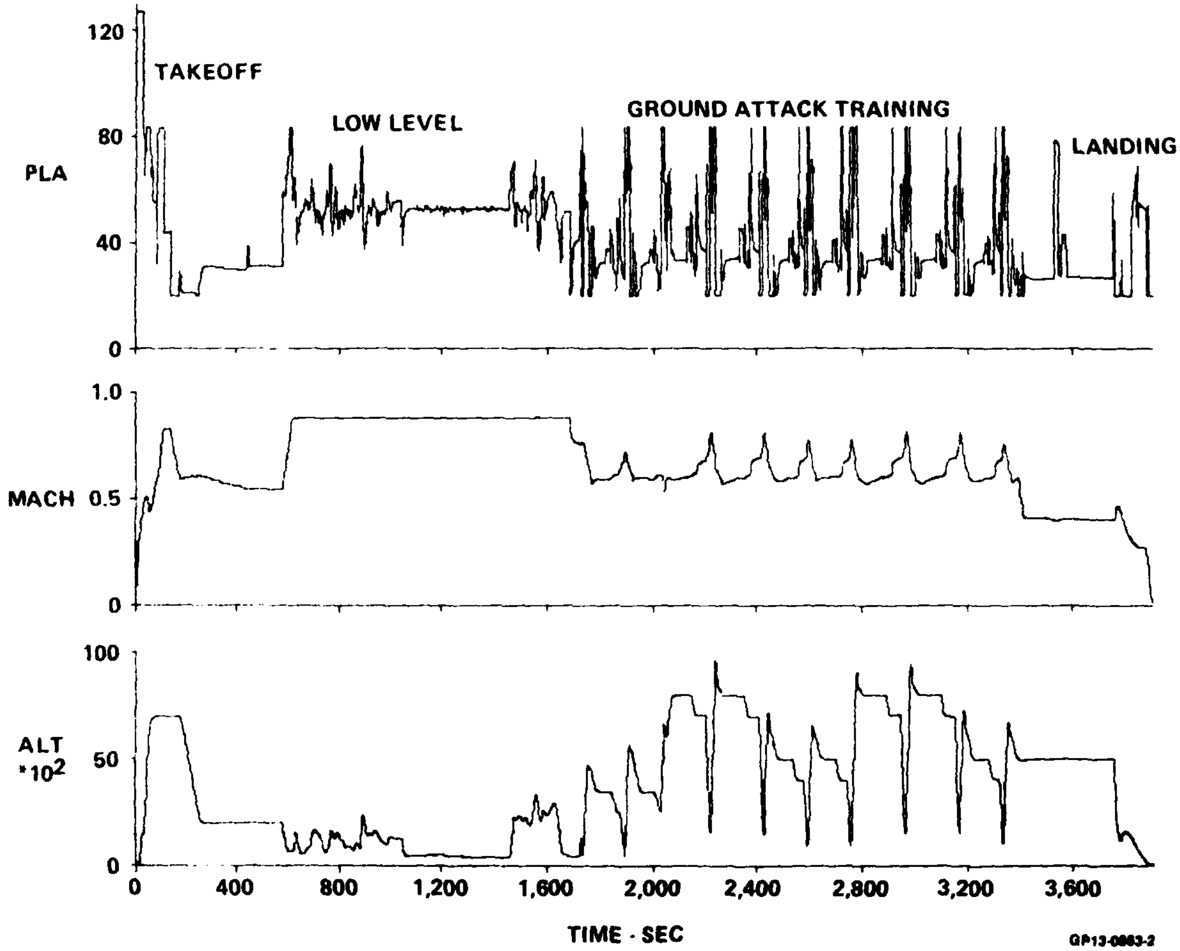
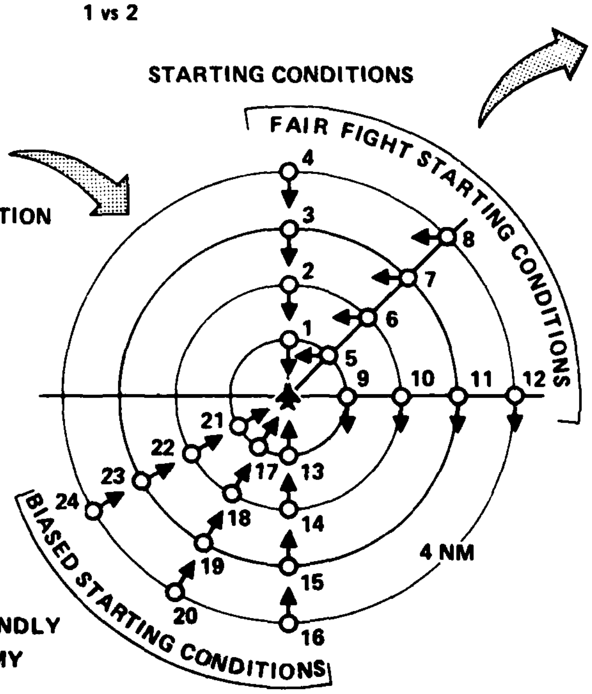


FIGURE 9
AIR COMBAT MODEL

INPUT

- WEIGHT
- THRUST = $\int$ (M, ALT, PLA)
- DRAG = $\int$ (C_L, M)
- V_{MAX} = $\int$ (ALT)
- THRUST RESPONSE
- n_{zMAX} = $\int$ (WEIGHT)
- ROLL RATES
- MAX ROLLING ACCELERATION
- SPEED BRAKE
- ARMAMENT
  - LAUNCH ENVELOPE
  - LETHALITY
  - ROUNDS

FORCE	***RATIO (M vs N)***
1 vs 1	2 vs 1
1 vs 2	



OUTPUT

- FUEL CONSUMED
- THROTTLE CYCLES
- INT+ TIME

PLUS EFFECTIVENESS PARAMETERS

36 ENGAGEMENTS

- 12 BIASED FRIENDLY
- 12 BIASED ENEMY
- 12 NEUTRAL

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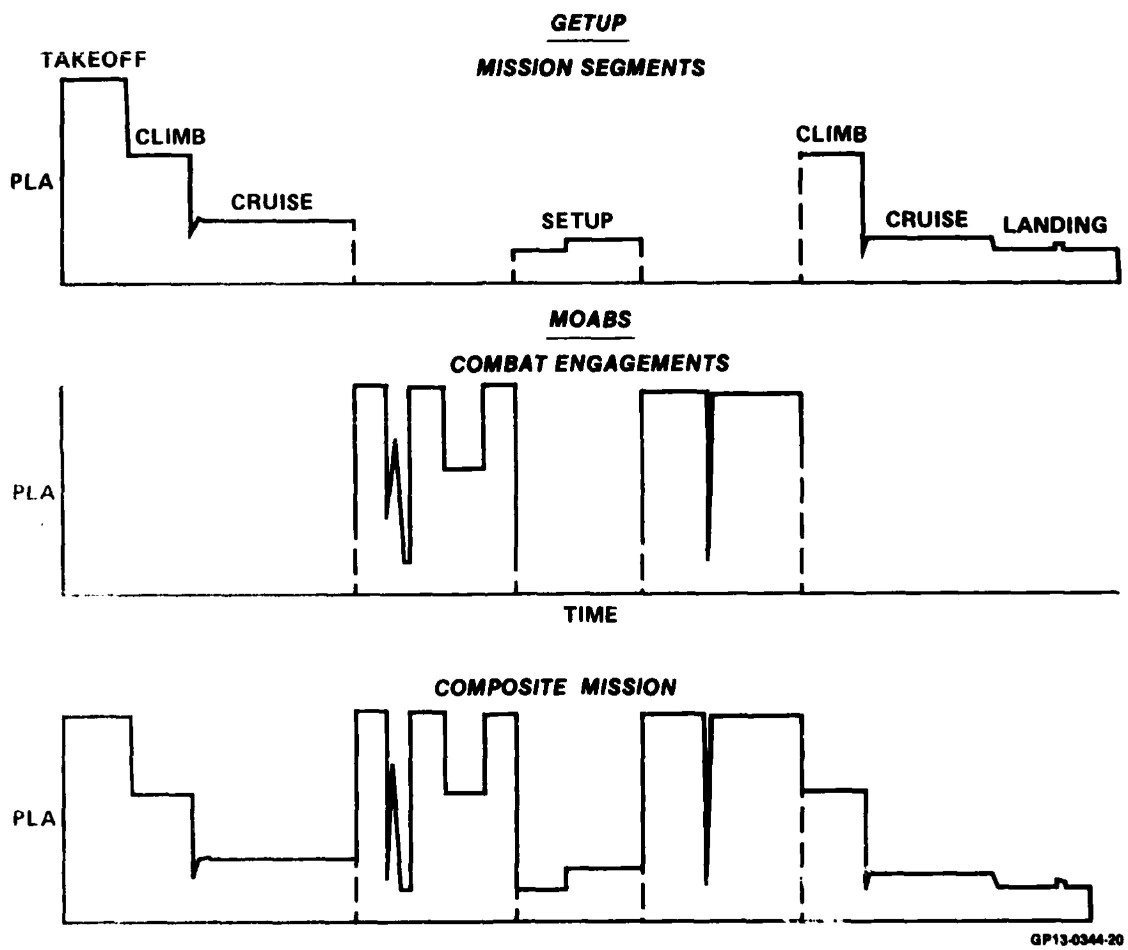
FIGURE 10
AIR COMBAT MISSION BUILDUP



A significant percentage of the total engine operating hours are spent in pre- and post-flight ground operations. Figure 11 shows pre- and post-flight times for several current aircraft. It represents 33% of the total mission time for the F-15, 31% for the F-111 and 37% for the F-4.

Pre-flight time consists of engine start and warm-up, avionics warm-ups and checks, weapons arming and checks, and time spent taxiing and awaiting clearance for takeoff. In general, Figure 11 shows that a significant factor in preflight time is the quantity and complexity of the avionics and weapons systems. This is illustrated by comparing F-5 preflight time (15 minutes) with F-111 preflight time (40 minutes) at Nellis AFB. A breakdown of the ground time spent in checking F-111 systems is shown in Figure 12.

FIGURE 11
PRE AND POSTFLIGHT OPERATIONS

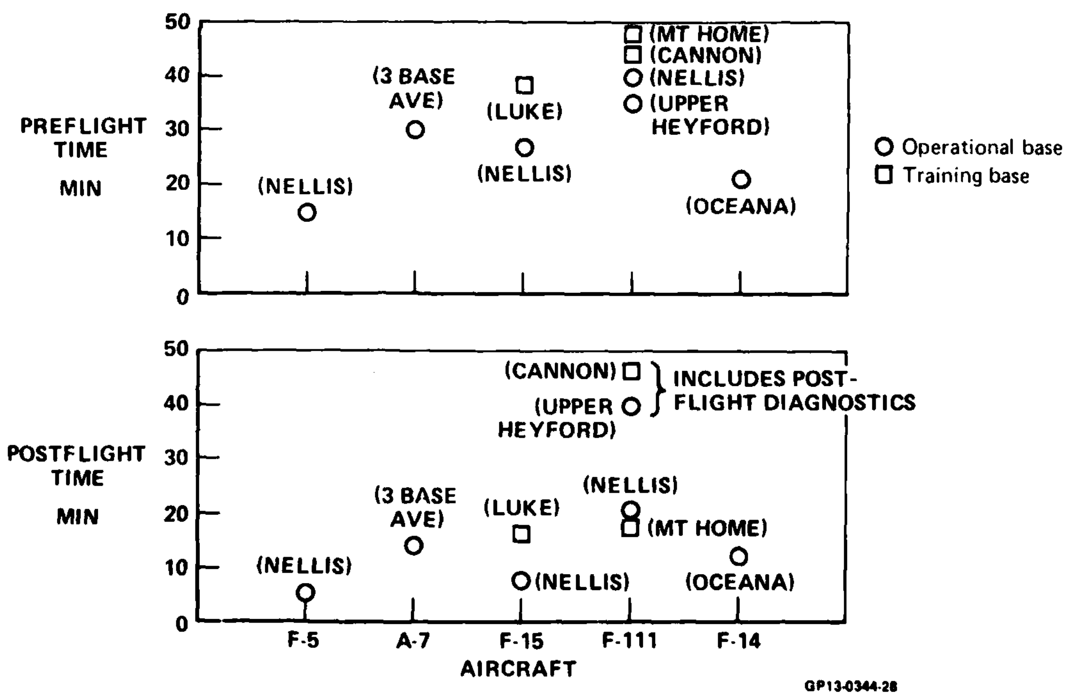


FIGURE 12
F-111 PREFLIGHT TIME BREAKDOWN

	MINUTES
INS WARM UP AND ALIGNMENT	15
TERRAIN FOLLOWING RADAR CHECKS	3
WEAPONS ARMING AND VISUAL CHECKS	10
OTHER (TAXI, CLEARANCE, ETC)	15 - 20
TOTAL	43 - 48

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It is expected that improvements in Inertial Navigation Systems (INS) will eliminate or greatly reduce the time required for INS warm-up and alignment. A preflight time of 30 minutes was selected for advanced fighter ground operation representations. Post-flight time is less system dependent. A post-flight time of 10 minutes was used in this study.

Despite the large percentage of mission time spent on the ground, very few engine damaging events (i.e. Type III cycles and hot time) occur during this operation. Figure 13 shows some representative pre- and post-flight throttle transients incurred during aircraft taxi operations. The severity and duration of the throttle cycles are functions of the thrust-to-weight of the aircraft, but, in general, these transients are not significant compared to the cycles incurred during flight.

Engine operation during maintenance and engine trim is currently a significant portion of the engine duty cycle. Estimates for the F100 engine have indicated that approximately 3% of the Type III throttle cycles and 10% of the hot time is accumulated during maintenance and trim operations, Reference 5. It is anticipated that future engines will have self-trimming controls which will reduce the impact of engine maintenance on engine duty cycles to less than 1% of the throttle cycles and about 1% of the total hot time accumulation.

3.4 <u>THROTTLE CYCLE AND HOT TIME COUNTING ROUTINE</u> - Throttle time histories are computed in the usage models for each of the peacetime missions. These time histories are then input into the COUNT program which computes the throttle cycle and hot time accumulations. The throttle cycle counting technique used in COUNT is the Rainflow Cycle Counting method described in Reference 6.

The COUNT program counts Type I cycles, Type III cycles, 10 partial cycles, and hot time accumulations for six different PLA levels. Appendix A reviews the cycle counting procedure used in the COUNT program.

FIGURE 13
PRE/POSTFLIGHT THROTTLE EXCURSION

PREFLIGHT THROTTLE EXCURSIONS			
AIRCRAFT	ΔPLA	Δ% ROTOR SPEED	NUMBER OF CYCLES
A-7	20°	25	4
A-10	28°	29	2
F-14	10°	25	2
F-111	–	15	6

POSTFLIGHT THROTTLE EXCURSIONS			
AIRCRAFT	ΔPLA	Δ% ROTOR SPEED	NUMBER OF CYCLES
A-7	–	5	2
A-10	10°	12	2
F-14	10°	25	1

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4. PEACETIME MISSION DEFINITIONS

Peacetime mission descriptions were developed by reviewing mission data for current fighters and projecting changes in training requirements due to advanced weapon system capabilities. The mission analysis identified the peacetime mission types and frequencies, the training maneuvers for each mission segment and the flight path and maneuver inputs for the usage models.

Paragraph 4.1 briefly reviews the advanced technology features of the LUCID aircraft that are expected to affect the training missions. Paragraph 4.2 describes the selection of mission types and frequencies and Paragraph 4.3 reviews the flight profiles and training maneuvers contained in each training mission. The aircraft configuration analyzed in LUCID is an advanced tactical strike aircraft which is described in Section 5.

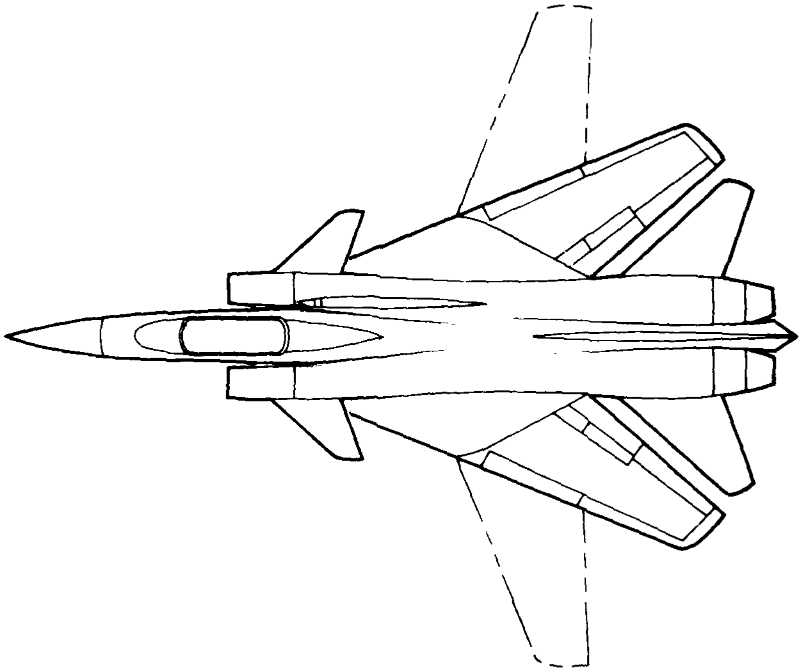
4.1 <u>ADVANCED WEAPON SYSTEM TECHNOLOGIES</u> - The weapon system technologies employed in the aircraft selected for the LUCID study are shown in Figure 14. These technology features were reviewed to identify potential impacts on peacetime training. The aircraft contains an advanced avionics suite, including a synthetic aperture radar, integrated threat detection and countermeasures, and an integrated information management system. The increased complexity of the avionics suite and increased reliance on avionics for acquiring, identifying and tracking ground targets are expected to affect training requirements.

Advanced air-to-surface missiles are also employed. The primary ground attack mode for the LUCID aircraft is a low level, transonic weapon delivery and the alternate attack mode is a high altitude, supersonic weapon delivery. Training will be required in both weapon delivery techniques. Figure 15 summarizes the training requirements associated with the high altitude weapon delivery.

4.2 <u>MISSION TYPES AND FREQUENCIES</u> - The approach used to select peacetime mission types and frequencies is illustrated in Figure 16. An extensive data base was assembled including mission data from previous usage studies (References 7-9), base visits by MCAIR and P&WA personnel, pilot interviews, flight manuals, training manuals, base operations manuals and MCAIR product support data for F-4 and F-15 aircraft. The data base is summarized in Figure 17. Mission data are available for F-15, F-4, A-7, F-111, A-10 and F-5 aircraft.

A generalized set of peacetime missions and frequencies for current attack aircraft were identified and are shown in Figure 18. Mission frequencies are presented for transitional training bases, operational training bases, and a composition mission syllabus.

FIGURE 14
LUCID AIRCRAFT TECHNOLOGY FEATURES



AIRFRAME

"THREE-SURFACE" ARRANGEMENT TO MINIMIZE DRAG DUE TO LIFT
VARIABLE WING SWEEP TO REDUCE SUPERSONIC DRAG
RELAXED STATIC STABILITY FOR REDUCED TRIM DRAG
CONFORMAL WEAPONS CARRIAGE FOR LOW SUPERSONIC DRAG

AVIONICS

MULTI-MODE, ALL-WEATHER, SYNTHETIC APERTURE RADAR
INTEGRATED THREAT DETECTION AND COUNTERMEASURES
INTEGRATED INFORMATION MANAGEMENT SYSTEM

WEAPONS

STANDOFF AIR-TO-SURFACE MISSILE (2,000 LB)
MEDIUM RANGE AIR-TO-AIR MISSILE (275 LB)
25 mm GUN

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FIGURE 15
TRAINING REQUIREMENTS

AVIONIC TRAINING REQUIRMENTS

- **SAR**
  - TARGET IDENTIFICATION/ACQUISITION
- **RHAWS**
  - CHECKLIST ACTION ITEMS - SIMULATOR TRAINING
- **ECM**
  - CHECKLIST ACTION ITEMS - SIMULATOR TRAINING

WEAPON DELIVERY TRAINING REQUIREMENTS

- **TASKS**
  - SEQUENCING/COMPLETION OF CHECKLIST ITEMS WITHIN FIRING ENVELOPE (EVASIVE MANEUVERS, TARGET ACQUISITION, TARGET TRACKING)
- **REQUIREMENT**
  - REALISTIC TIME/WORKLOAD

PROJECTED TRAINING MISSION

- **SUBSONIC**
  - INSTRUMENT/PROFICIENCY MISSION
    - SAR TARGET IDENTIFICATION/ACQUISITION
    - NO BOMBING RANGES REQUIRED
    - VARIETY OF TARGETS
- **SUPERSONIC**
  - HIGH ALTITUDE GROUND ATTACK TRAINING MISSION
    - SIMULATED WEAPONS DELIVERY
    - LIMITED RANGES/TARGETS

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FIGURE 16
DEFINITION OF MISSION TYPES AND FREQUENCIES

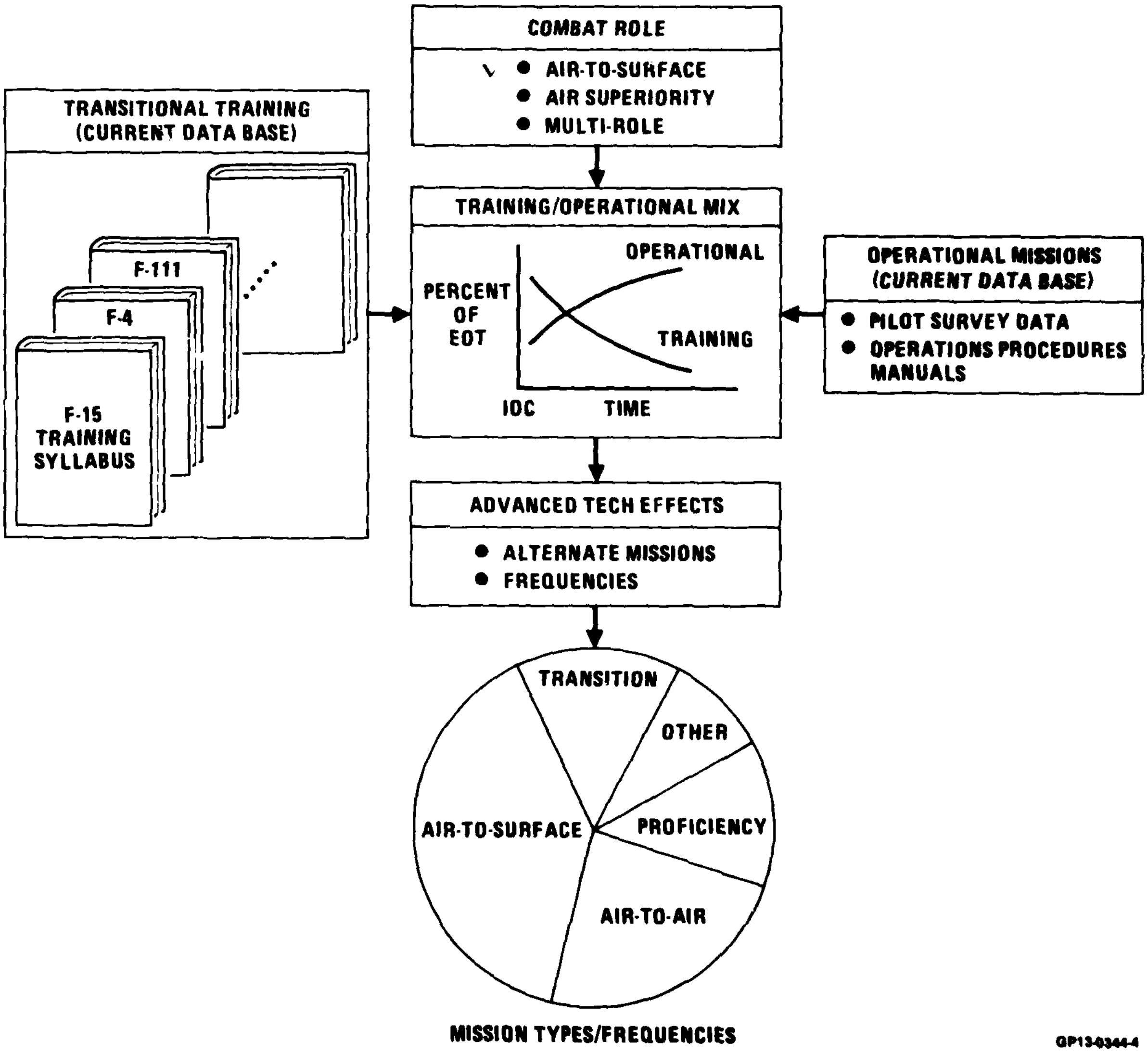

FIGURE 17
SUMMARY OF AVAILABLE MCAIR OPERATIONAL AIRCRAFT MISSION SYLLABUS DATA

AIRCRAFT	UNITS, BASE	MISSION MIX	MISSION DESCRIPTIONS	GROUND OPERATIONS	ENGINE UTILIZATION	COMMENTS
F-4C/D/E PHANTOM II	1st TFW MACDILL AFB, FL				√	F-4 TRAINING, PRIOR TO TRANSITION TO F-15
	35th TFW GEORGE AFB, CA				√	F-4 TRAINING
	31st TFW HOMESTEAD AFB, FL				√	F-4 OPERATIONAL FIGHTER
	33rd TFW EGLIN AFB, FL	√	√		√	F-4 OPERATIONAL FIGHTER
	57th FWW NELLIS AFB, NV	√	√		√	F-4 INSTRUCTOR TRAINING
	183rd TFG SPRINGFIELD, IL	√	√			AIR NATIONAL GUARD
F-5E TIGER II	64th FWS NELLIS AFB, NV	√	√	√	√	AGGRESSOR SQUADRON
F-15A/B EAGLE	1st TFW LANGLEY AFB, VA	√	√	√	√	ACTUAL ENGINE UTILIZATION DATA FROM EHR
	36th TFW BITBURG AB, FRG	√	√	√	√	
	58th TFTW LUKE AFB, AZ	√	√	√	√	461st TFS, 555th TFS
F-111A/D/E/F	20th TFW UPPER HEYFORD, UK	√	√		√	F-111E
	27th TFW CANNON AFB, NM	√	√		√	F-111D
	366th TFW MOUNTAIN HOME AFB, ID	√	√		√	F-111F
	474th TFW NELLIS AFB, NV	√	√		√	F-111A
F-100 D/F SUPER SABRE	131st TFW ST. LOUIS, MO	√	√			AIR NATIONAL GUARD
F-14A TOMCAT	–	√	√		√	ACTUAL ENGINE UTILIZATION DATA FROM FULLY INSTRUMENTED AIRCRAFT NO. 20
A-7D CORSAIR II	354th TFW MYRTLE BEACH AFB, SC	√	√	√		VIETNAM WAR MISSIONS
	355th TFW DAVIS MONTHAN AFB, AZ	√	√	√		354th, 355th TFW PRIOR TO A-10 TRANSITION
	23rd TFW ENGLAND AFB, LA	√	√	√		
A-10A THUNDERBOLT II	355th TFW DAVIS MONTHAN AFB, AZ		√			333rd TFTS, 358th TFTS
FB-111A	380th BW PLATTSBURG AFB, NY	√	√		√	

Legend:

BW: Bombardment Wing
FWS: Fighter Weapon Squadron
FWW: Fighter Weapon Wing
TFS: Tactical Fighter Squadron
TFW: Tactical Fighter Wing
TFTS: Tactical Fighter Training Squadron
TFTW: Tactical Fighter Training Wing
TRTS: Tactical Reconnaissance Training Squadron
TRW: Tactical Reconnaissance Wing

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FIGURE 18
PEACETIME MISSION TYPES/FREQUENCIES
Current Data Base: USAF Tactical Strike Aircraft

MISSION	OPERATIONAL TRAINING	TRANSITIONAL TRAINING	COMPOSITE
1. GROUND ATTACK	70%	60%	67%
2. DEFENSIVE AIR COMBAT	20%	13%	18%
3. INSTRUMENT/PROFICIENCY	7%	–	5%
4. FAMILIARIZATION	–	24%	7%
5. FUNCTIONAL CHECK FLIGHT	2%	2%	2%
6. FERRY/CROSS COUNTRY	1%	1%	1%

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Transitional training missions familiarize pilots with a new aircraft, including pilots from undergraduate pilot training, experienced pilots transitioning from another aircraft, and pilots being trained as instructors. The aircrew training course and training missions required to complete these courses are described in the Tactical Air Command Manual (TACM) 51-50. Figure 19 summarizes a typical air-to-ground training course for F-4 pilots. The course descriptions are used to identify the mission types and frequencies flown by units such as the 58th Tactical Training Wing at Luke Air Force Base (AFB).

Operational missions are conducted to maintain the proficiency levels of experienced pilots in performing their assigned combat mission and to develop and refine combat tactics. The mission types and frequencies are thus a function of the combat role of the aircraft. These are generalized mission mixes and the missions and frequencies vary from base to base. In addition, specialized missions are conducted during specialized training exercises such as Red Flag and advanced tactics development at Nellis AFB, Maple Flag, and other joint training exercises.

Engine usage rates vary for each type of training. Figure 20 shows actual engine usage data for the F100 engine during F-15 transitional, operational, and specialized training missions. More throttle cycles are accumulated during transitional training due to factors such as increased landing practice, formation flight training for inexperienced pilots and aerobatics.

FIGURE 19
TRAINING COURSE SUMMARY F-4D/E

MISSION TYPE	NUMBER OF MISSIONS	MISSION LENGTH (HR)	(1) CONFIGURATION	DYNAMIC MANEUVERS
TRANSITIONAL TRAINING (TR)	13	1.5 HR	1	TAKEOFFS, TOUCH AND GOES AEROBATICS, STEEP TURNS, CONFIDENCE MANEUVERS (STALLS, UNUSUAL ATTITUDE RECOVERY)
BASIC FIGHTER MANEUVERS (BFM)	6	1.3	2	1 v 1, F-4 vs F-4
AIR COMBAT MANEUVERS (ACM)	3	0.8	2 OR 3	1 v 2, 2 v 1, F-4 vs F-4
DISSIMILAR AIR COMBAT MANEUVERS (DACM)	3	0.8	3	1 v 2, 2 v 1, F-4 vs F-4 + AGGRESSOR
GROUND ATTACK RADAR (GAR)	5	1.5	4 OR 5	ACCELS/DECELS, TURNS RADAR/INERTIAL LOW LEVEL NAVIGATION
GROUND ATTACK (GA)				
– WITHOUT REFUELING	9	1.3	6	DIVE BOMBING, DIVE TOSS, LOW ALTITUDE STRAFE, JOIN-UPS
– WITH REFUELING	6	2.3	6	
GROUND ATTACK TACTICAL (GAT)	8	1.3	6	LOW ALTITUDE FORMATION FLYING, TACTICAL DELIVERIES

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(1) Configurations

1 Full internal fuel + 2 x 370 gal. tanks
2 Full internal fuel + 2 x 370 gal. tanks + 1 x captive AIM-9 J/L + 3 x AIM-9 missile wafers + 4 x AIM-7 missile wafers
3 Full internal fuel + 1 x captive AIM-9 J/L + 3 x AIM-9 missile wafer + 4 x AIM-7 missile wafers
4 Full internal fuel + 2 x 370 gal. tanks + 1 x 600 gal. tank + 1 x SUU-20 practice bomb dispenser + 6 x MK-106 practice bombs
5 Full internal fuel + 2 x 370 gal tanks + 1 x SUU-20 practice bomb dispenser + 6 x MK-106 practice bombs
6 Full internal fuel + 2 x 370 gal. tanks + 2 x SUU-20 practice bomb dispenser + cannon w/150 rounds target practice ammo, + 12 x BDU-33 practice bombs

Figure 21 shows a breakdown of the F-15 flight hours for transitional, operational, and specialized training. Early operation is largely devoted to transitioning pilots to the new aircraft. As aircraft production increases and the aircraft is deployed to more operational bases, operational training increases. The steady state breakdown for the F-15 is approximately 70% operational training, 20% transitional training, and 10% other missions (e.g. Nellis AFB, Edwards AFB).

The selection of a mission syllabus to calculate an engine duty cycle must consider the weighting provided for transitional, operational, and specialized missions. Designing to the most severe usage (i.e. specialized training) may result in an unacceptable performance penalty, while designing to the highest frequency usage (i.e. operational training) may result in engine durability deficiencies in certain training situations. An assessment of the cost and performance trades associated with these options is needed.

FIGURE 20
USAGE COMPARISON FOR OPERATIONAL AND TRANSITIONAL TRAINING

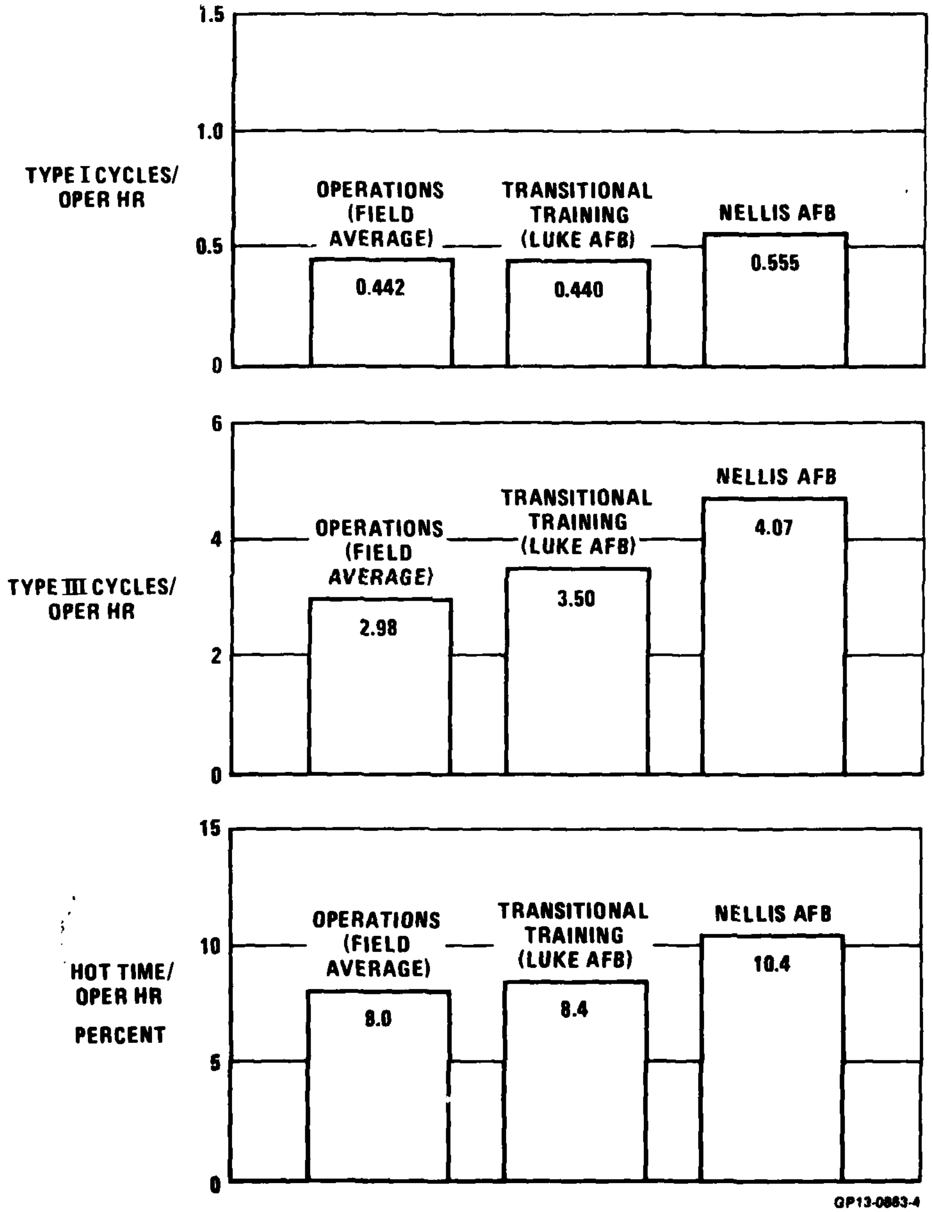
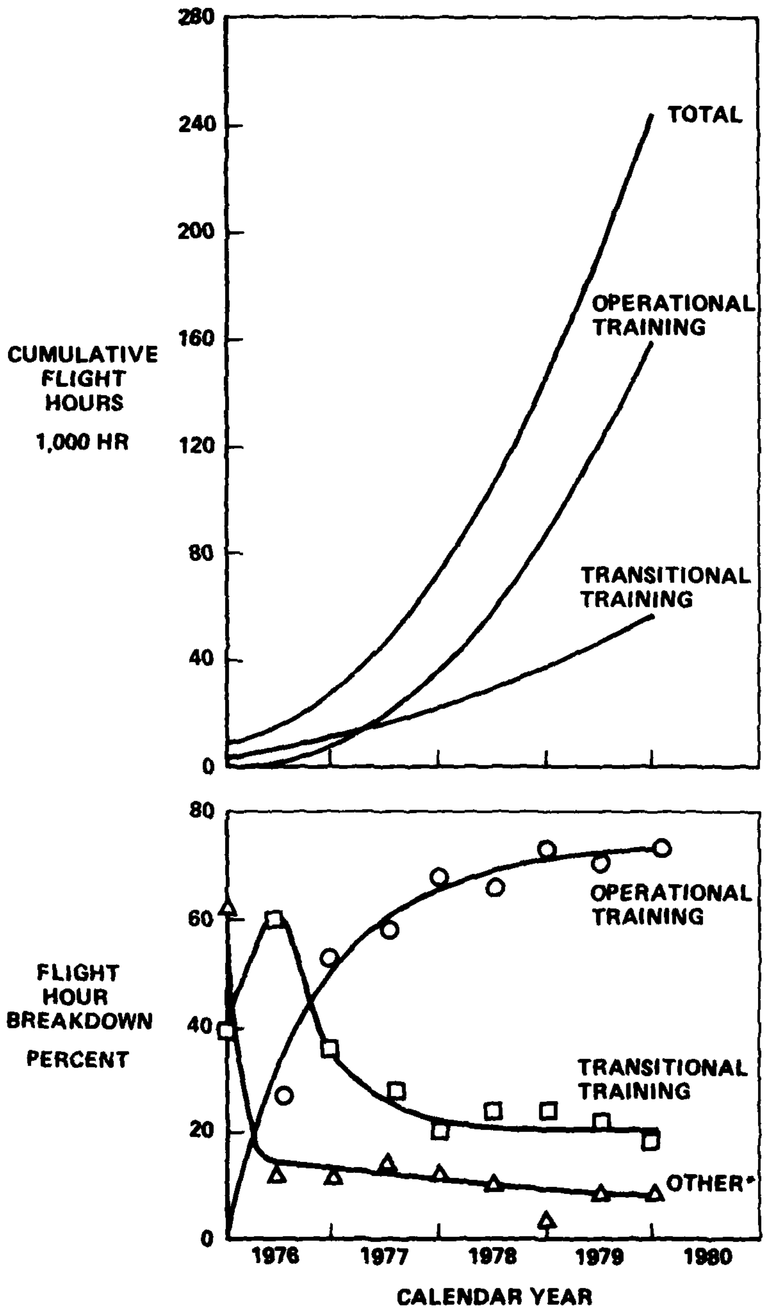


FIGURE 21
F-15 FLIGHT HOUR DISTRIBUTIONS



*Other - Nellis, Edwards, . . .

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In the absence of such data, a weighting represented by the flight hour breakdown shown in Figure 21 was selected for the initial usage calculations. This weighting represents a field average usage but would not necessarily reflect the usage experienced by individual engines. The performance and life cycle cost impact of this option as well as the other options should be explored further.

The training requirements associated with the advanced weapon system technologies discussed in Paragraph 4.1 affected the definition of peacetime missions, as summarized in Figure 22. A high altitude, supersonic mission was added to provide training in this weapon delivery technique. A typical weapon delivery pattern in the high altitude supersonic attack mission is shown in Figure 23. The important elements of the weapon delivery include target acquisition, identification and tracking, ground and air threat tracking and avoidance, and missile launch and guidance. Manned simulations of these weapon deliveries have shown that one of the principal difficulties was firing the missile within the proper launch envelope, due to the work loads and time constraints. It is anticipated that flight training at supersonic speeds will be required to maintain proficiency in this weapon delivery.

FIGURE 22
PEACETIME MISSIONS AND FREQUENCIES FOR ADVANCED TACTICAL STRIKE AIRCRAFT

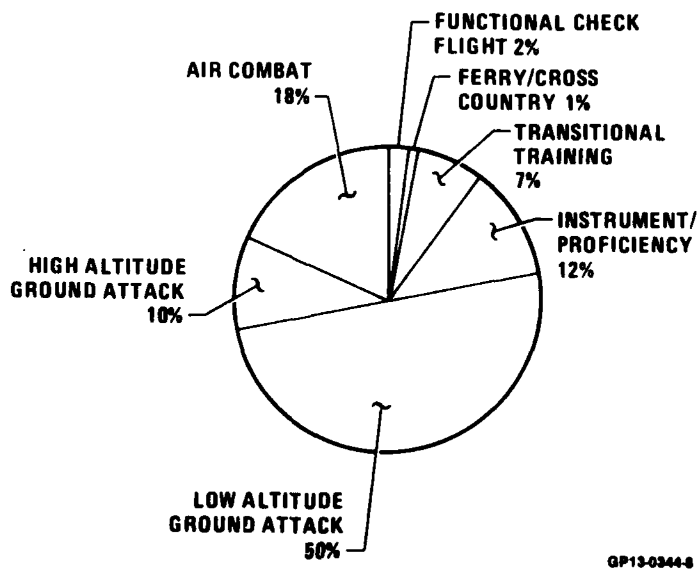
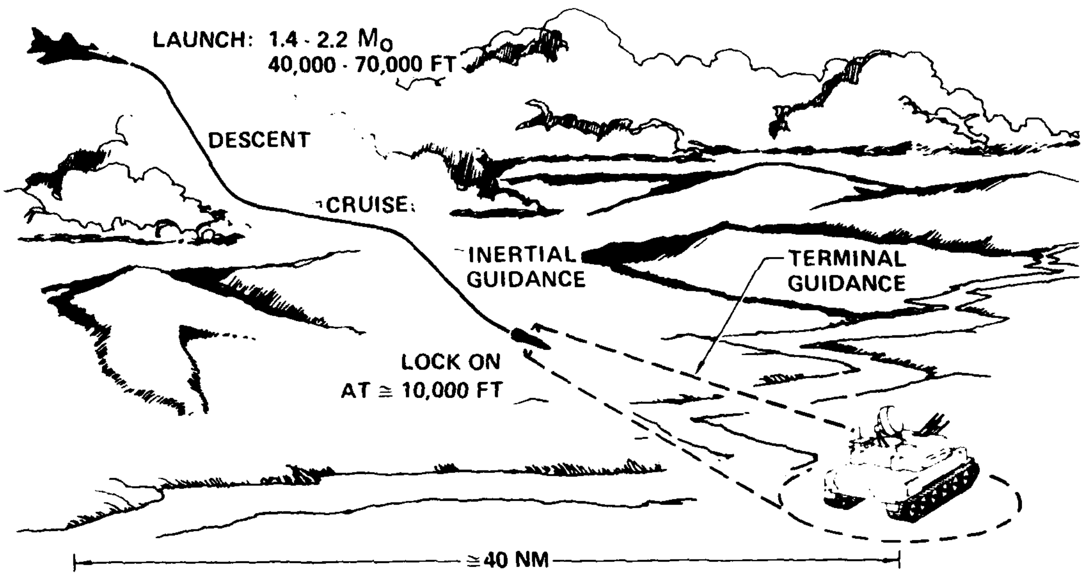


FIGURE 23
ADVANCED AIR-TO-SURFACE WEAPON DELIVERY



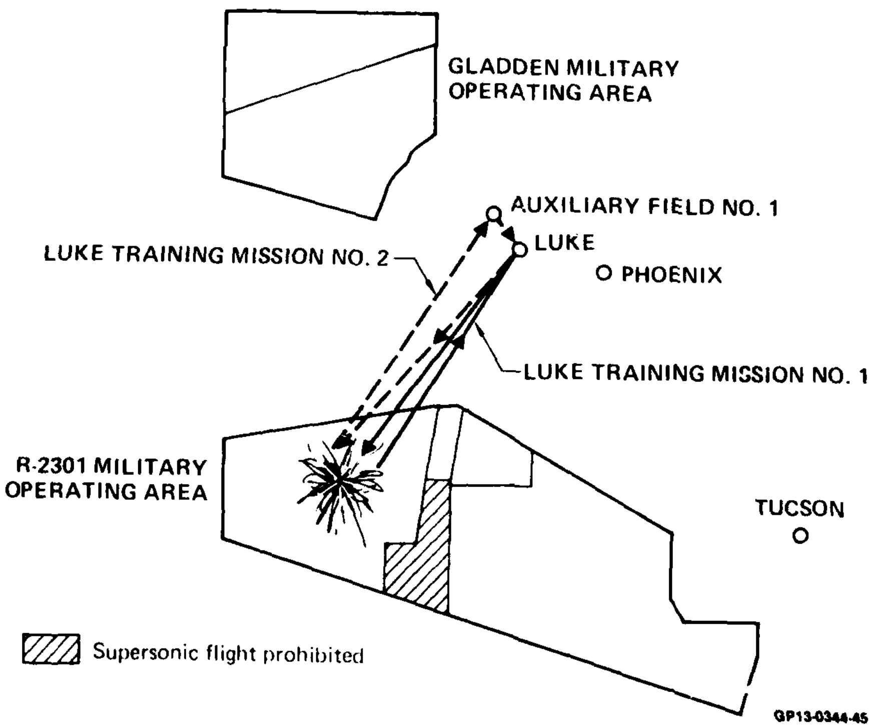
The mission frequency selected for this mission was limited to 10% because it is an alternate ground attack mode for the LUCID aircraft and because of the limited availability of supersonic training ranges. A 50% frequency was selected for the low altitude attack mission. Thus, a total weighting of 60% is provided for ground attack training missions, a reduction of 7% from the mission syllabus for current strike aircraft.

The additional 7% percent was applied to the proficiency mission. Avionics training in acquiring, identifying and tracking a variety of realistic targets was added to this mission. The mission frequencies for the defensive air combat, transitional training functional check flight and ferry missions are unchanged from the original data base.

4.3 <u>MISSION PROFILES</u> - The mission profiles for each peacetime mission must be defined, including the training maneuvers performed in each mission segment and the flight path and maneuver inputs required to simulate each mission in the usage analysis models. Each mission consists of a takeoff and climb segment, a cruise to a training area, a sequence of training events, a cruise back to the base and a descent and landing segment.

The flight profiles selected for the transitional training missions are based on missions flown at Luke AFB. Luke was selected because it is the largest USAF training base and MCAIR has developed an extensive data base relating to training operations at Luke. The detailed mission descriptions available for Luke will provide a realistic representation of engine usage during transitional training. Figure 24 shows the routes and training ranges selected for the basic and advanced transitional training missions.

FIGURE 24
TRAINING RANGES AND MISSION ROUTES AT LUKE AFB



Eglin AFB was selected to represent the operational mission profiles. Eglin AFB was selected because detailed mission data is available for Eglin and because its proximity to the training ranges results in a more demanding usage environment. Short cruise distances to the training ranges result in shorter mission times and thus, more Type I cycles (engine starts) per flight

hour. In addition, more fuel is available for the training maneuvers, resulting in more Type III cycle and hot time accumulations per flight hour. Figure 25 shows, for several F-15 bases, a plot of mission time versus cruise distances from the base to the range. Figure 26 shows the routes and training ranges selected for the operational missions at Eglin AFB.

The specific flight profiles and training maneuvers selected for the peacetime missions are discussed in Appendix B.

FIGURE 25
EFFECT OF CRUISE DISTANCE ON FLIGHT HOURS PER MISSION

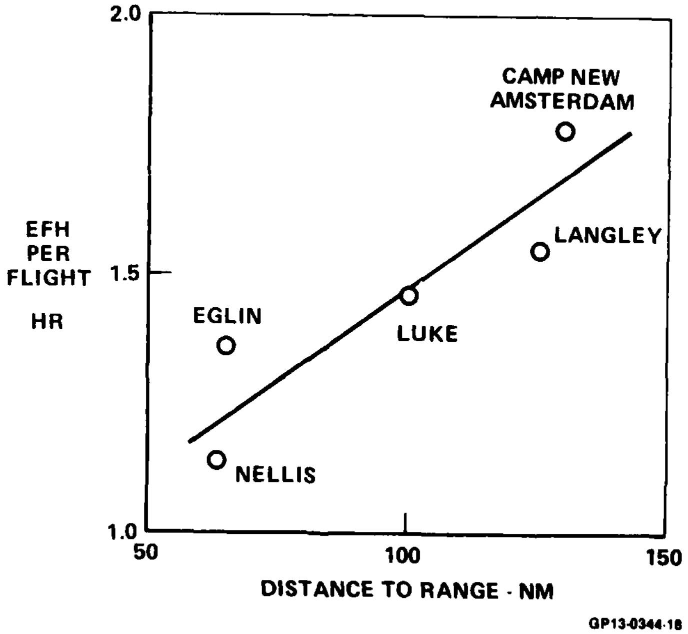


FIGURE 26(a)
TRAINING RANGES AND MISSION ROUTES AT EGLIN AFB

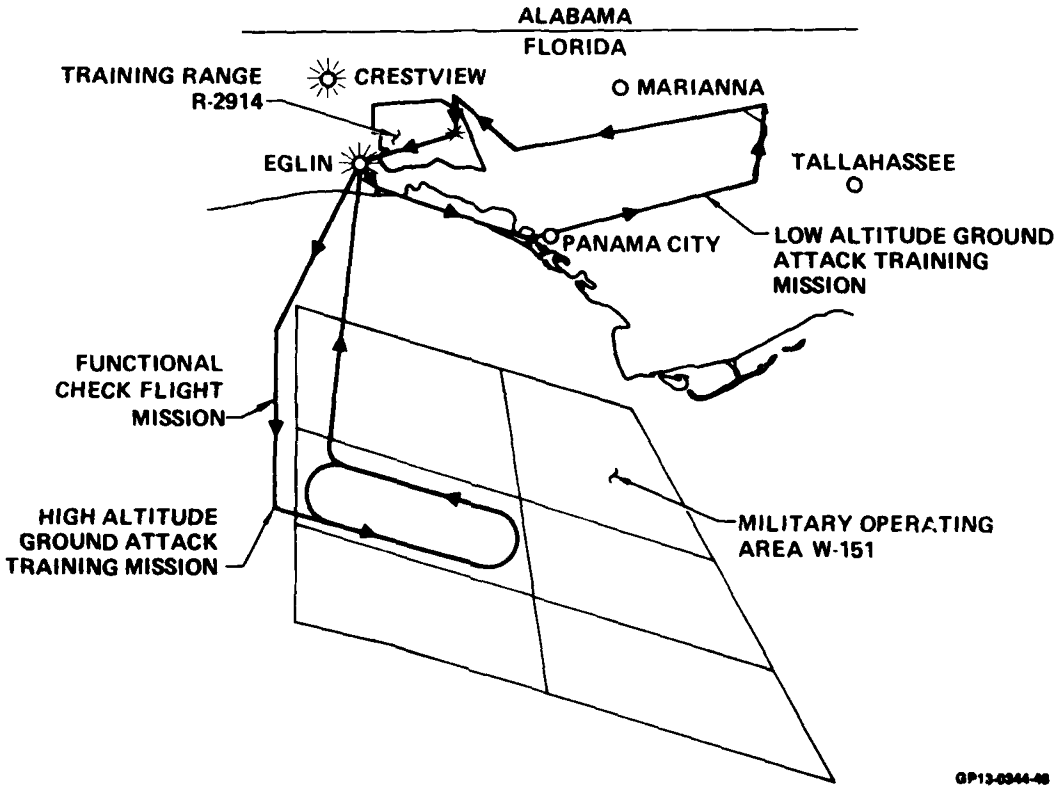
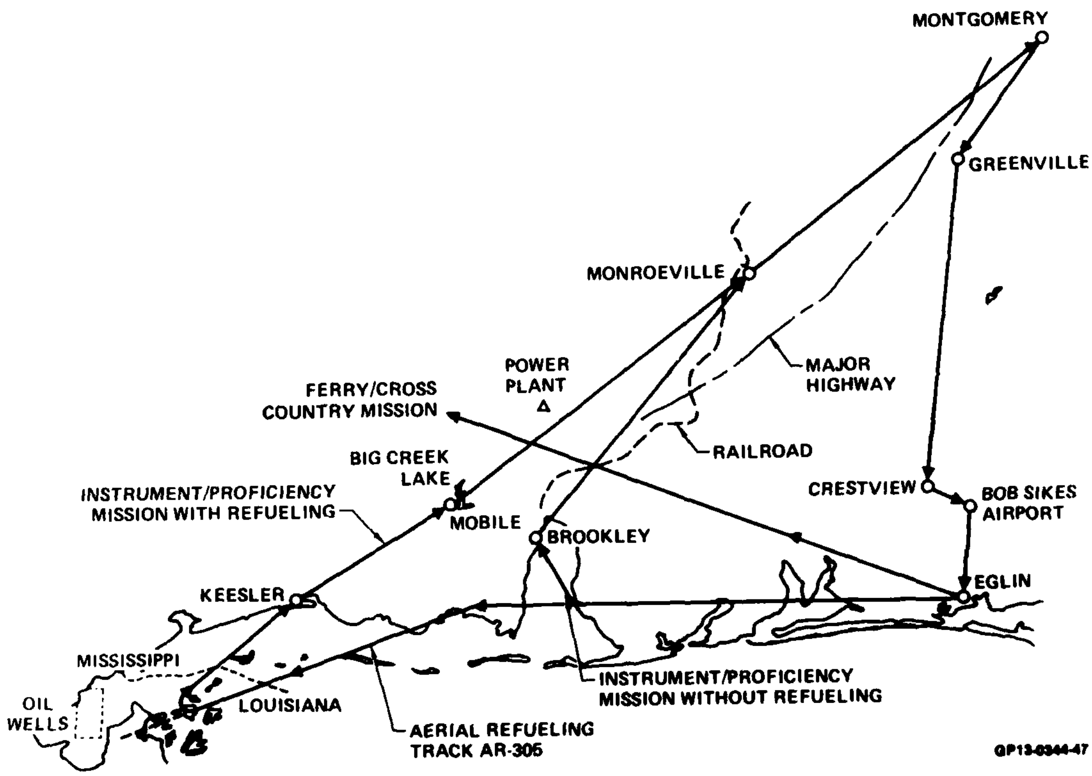


FIGURE 26(b)
MISSION ROUTES FOR INSTRUMENT/PROFICIENCY AND FERRY/CROSS COUNTRY MISSIONS



5. BASELINE AIRCRAFT

An advanced tactical strike aircraft was selected for this study from an existing MCAIR data base. The selected configuration, Figure 27, is a variable sweep wing design developed in the Air-to-Surface (ATS) Technology Evaluation and Integration study conducted by MCAIR under AFFDL Contract Number F33615-76-C-3101, Reference 10.

The variable wing sweep provides a good blend of subsonic cruise and supersonic dash capability while also providing good high speed ride qualities at low altitude, good maneuverability for self defense capability, and reduced takeoff and landing distances. These advantages are offset by the structural weight and fuselage volume penalties associated with the wing sweep mechanism.

The weapon system technologies included in the baseline aircraft are based on an approximate IOC date of 1995. The key technology features of this configuration were shown previously in Figure 14.

A number of alternative weapon delivery tactics are currently being investigated for advanced tactical strike aircraft. Two potential strike missions are (1) a high altitude, supersonic penetration and weapons delivery and (2) a low altitude, transonic penetration and weapons delivery. The low altitude strike mission was selected as the sizing mission for the baseline aircraft and the high altitude strike mission was selected as an alternate. The design mission and alternate mission are summarized in Figure 28.

Figure 29 shows the maneuverability requirements selected for the baseline aircraft. The excess P_S and sustained turn requirements at .9 Mach and 30,000 feet were selected to provide the aircraft self escorting capability with appropriate weapons.

The payload consists of two advanced air-to-surface weapons conformally carried on the fuselage centerline, two advanced medium range air-to-air missiles for self-defense and a 25 mm gun with 750 rounds of ammunition. The total payload weight is 5,000 lbs.

The propulsion system characteristics of the variable sweep wing aircraft are summarized in Figure 30.

FIGURE 27
DESIGN MISSION CONFIGURATION

WEAPONS: 2 x ADVANCED AIR-TO-SURFACE MISSILES
2 x MEDIUM RANGE AIR-TO-AIR
MISSILES, 25 mm GUN

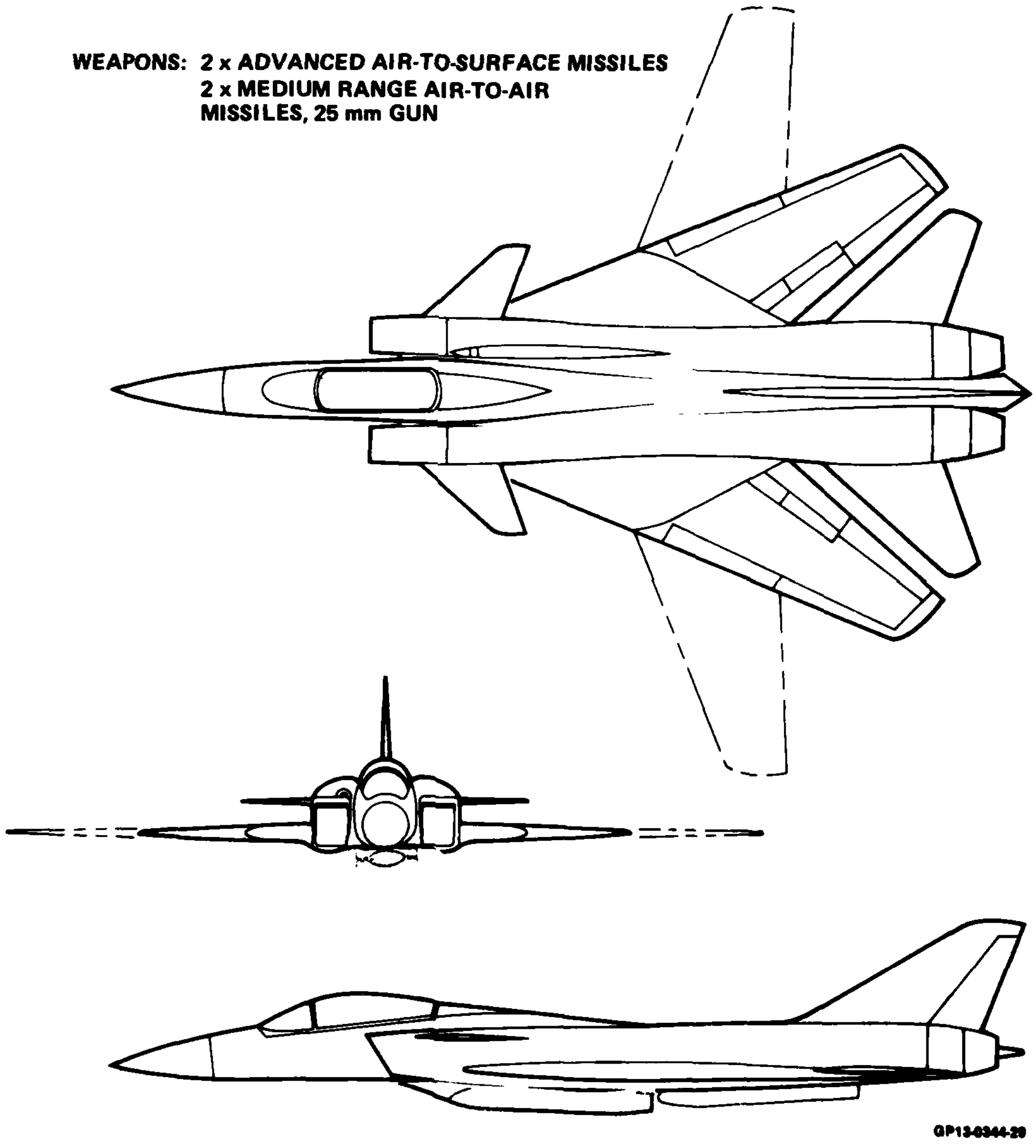
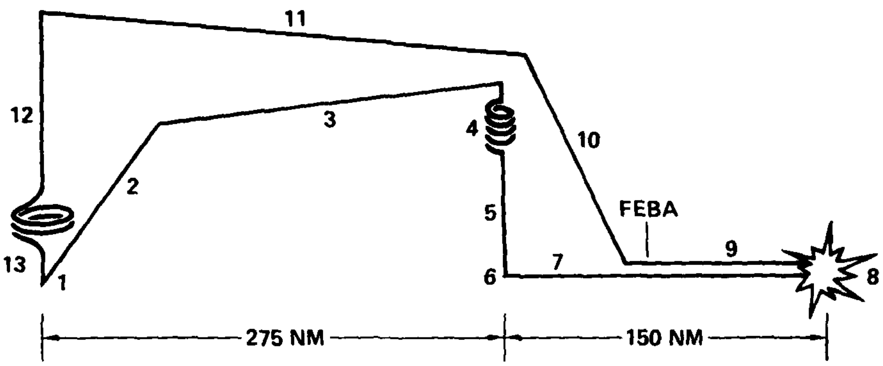


FIGURE 28(a)
LOW-ALTITUDE INTERDICTION: DESIGN MISSION



1	TAKEOFF	15 MIN AT MINIMUM POWER ACCELERATE TO CLIMB SPEED AT MAXIMUM POWER (NO DISTANCE CREDIT)
2	CLIMB	MINIMUM FUEL CLIMB AT INTERMEDIATE POWER
3	CRUISE	CRUISE TO 75 NM FROM FEBA AT MACH AND ALTITUDE FOR MAXIMUM RANGE
4	LOITER	10 MIN LOITER AT CRUISE ALTITUDE, MACH FOR MAXIMUM ENDURANCE
5	DESCENT	DESCENT TO SEA LEVEL (NO TIME, FUEL, OR DISTANCE CREDIT)
6	ACCELERATION	ACCELERATE FROM MACH 0.8 TO 0.95 AT INTERMEDIATE POWER
7	DASH	DASH TO TARGET AT MACH 0.95, SEA LEVEL
8	WEAPON DELIVERY	2 MIN AT MACH 0.95, SEA LEVEL, SEP = 150 FPS LAUNCH 2 AIR-TO-SURFACE MISSILES (4,000 LB); EXPEND 1/2 AMMO
9	DASH	DASH TO 25 NM BEYOND FEBA AT MACH 0.95, SEA LEVEL
10	CLIMB	MINIMUM FUEL CLIMB AT INTERMEDIATE POWER
11	CRUISE	CRUISE TO BASE AT MACH AND ALTITUDE FOR MAXIMUM RANGE
12	DESCENT	DESCENT TO SEA LEVEL (NO TIME, FUEL, OR DISTANCE CREDIT)
13	LANDING AND RESERVES	20 MIN LOITER AT SEA LEVEL, MACH FOR MAXIMUM ENDURANCE 5% OF INITIAL FUEL

Note: (2) Air-to-air missiles (550 lb) and 1/2 ammo retained throughout mission

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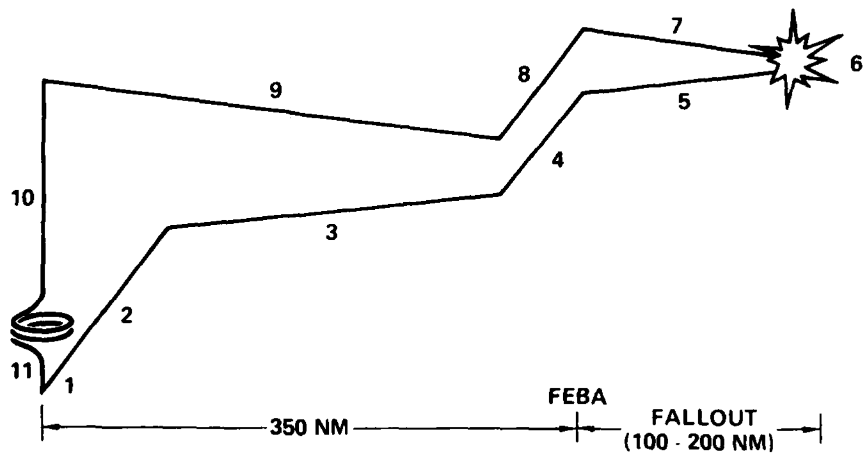
FIGURE 28(b)
HIGH-ALTITUDE GROUND ATTACK: ALTERNATE MISSION



1	TAKEOFF	15 MIN AT MINIMUM POWER ACCELERATE TO CLIMB SPEED AT MAXIMUM POWER (NO DISTANCE CREDIT)
2	CLIMB	MINIMUM FUEL CLIMB AT INTERMEDIATE POWER
3	CRUISE	CRUISE AT MACH AND ALTITUDE FOR MAXIMUM RANGE
4	CLIMB	MINIMUM FUEL CLIMB AT MAXIMUM POWER
5	DASH	DASH AT MACH 1.7, ALTITUDE FOR MAXIMUM RANGE
6	WEAPON DELIVERY	360° SUSTAINED TURN AT MACH 1.7, 50,000 FT, MAXIMUM POWER LAUNCH 2 AIR-TO-SURFACE MISSILES (4,000 LB)
7	DASH	DASH AT MACH 1.7, ALTITUDE FOR MAXIMUM RANGE
8	DESCENT	MAXIMUM RANGE DESCENT AT MINIMUM POWER
9	CRUISE	CRUISE AT MACH AND ALTITUDE FOR MAXIMUM RANGE
10	DESCENT	DESCENT TO SEA LEVEL (NO TIME, FUEL, OR DISTANCE CREDIT)
11	LANDING AND RESERVES	20 MIN LOITER AT SEA LEVEL, MACH FOR MAXIMUM ENDURANCE 5% OF INITIAL FUEL

Note: (2) Air-to-air missiles (550 lb) retained throughout mission

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FIGURE 29
FLIGHT PERFORMANCE GOALS

MANEUVERABILITY	
SUSTAINED TURN LOAD FACTOR	
MACH 0.9, 30,000 FT, MAX POWER(1)	3.5 g
SPECIFIC EXCESS POWER	
MACH 0.9, 30,000 FT, 1 g, MAX POWER(1)	400 FPS
MACH 0.95, SEA LEVEL, 1 g, INT POWER(2)	50 FPS

Note:
(1) 50% fuel, air-to-air missiles
(2) 80% fuel, air-to-surface and air-to-air missiles

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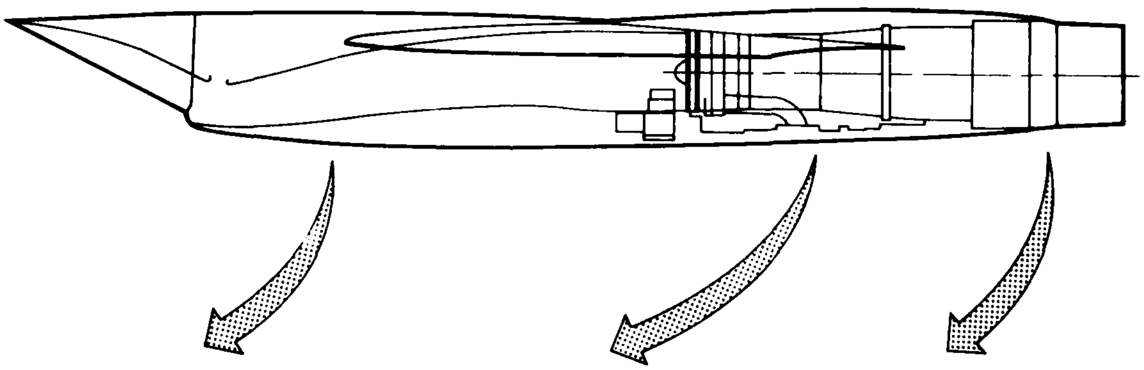
FIGURE 30
PROPULSION SYSTEM



INLET

- 2-D, FIXED RAMP
- MACH 2.0 DESIGN
- RAMP AND THROAT BLEED
- BYPASS AIRFLOW PROVISION

ENGINE

- P&WA 1155 PARAMETRIC ENGINE DECK
- MIXED-FLOW, TWIN-SPOOL TURBOFAN
- 1989 ENGINE QT

NOZZLE

- C-D, AXISYMMETRIC

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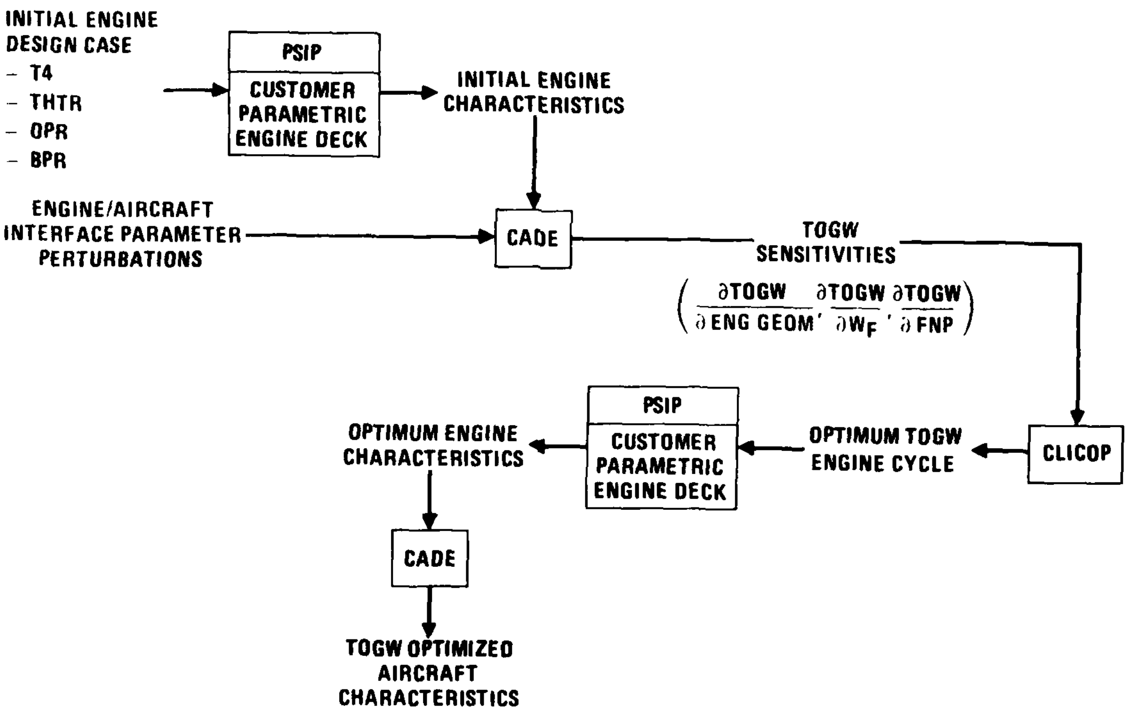
The aircraft was configured around an advanced P&WA turbofan engine obtained using the P&WA CCD 0234 parametric deck. In the LUCID study, the latest P&WA advanced engine technology base, represented by the P&WA CCD 1155 parametric deck, was used to provide consistency with the engine technology base currently being used in other advanced aircraft studies. Therefore, the engine cycle was reoptimized for the baseline aircraft and design mission using the P&WA CCD 1155 engine deck, and the aircraft was then resized with the optimized engine cycle. The approach used to reoptimize the engine cycle and resize the baseline aircraft is shown in Figure 31.

FIGURE 31
ENGINE CYCLE OPTIMIZATION PROCEDURE



PSIP - Propulsion system installed performance
CLICOP - Computerized linearized cycle optimization procedure
CADE - Computerized aircraft design evaluation

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The Computerized, Linearized, Cycle Optimization Procedure (CLICOP) was used to reoptimize the engine cycle. The CLICOP procedure, Figure 32, systematically varies engine cycle parameters and computes incremental changes in TOGW relative to the input engine cycle. The TOGW increments are computed using TOGW sensitivities to engine/airframe interface parameters (e.g. thrust, fuel flow, engine weight, engine geometry, etc.). These sensitivities are computed using the Computer Aided Design Evaluation (CADE) aircraft sizing program, Figure 33.

FIGURE 32
COMPUTERIZED LINEARIZED CYCLE OPTIMIZATION PROCEDURE

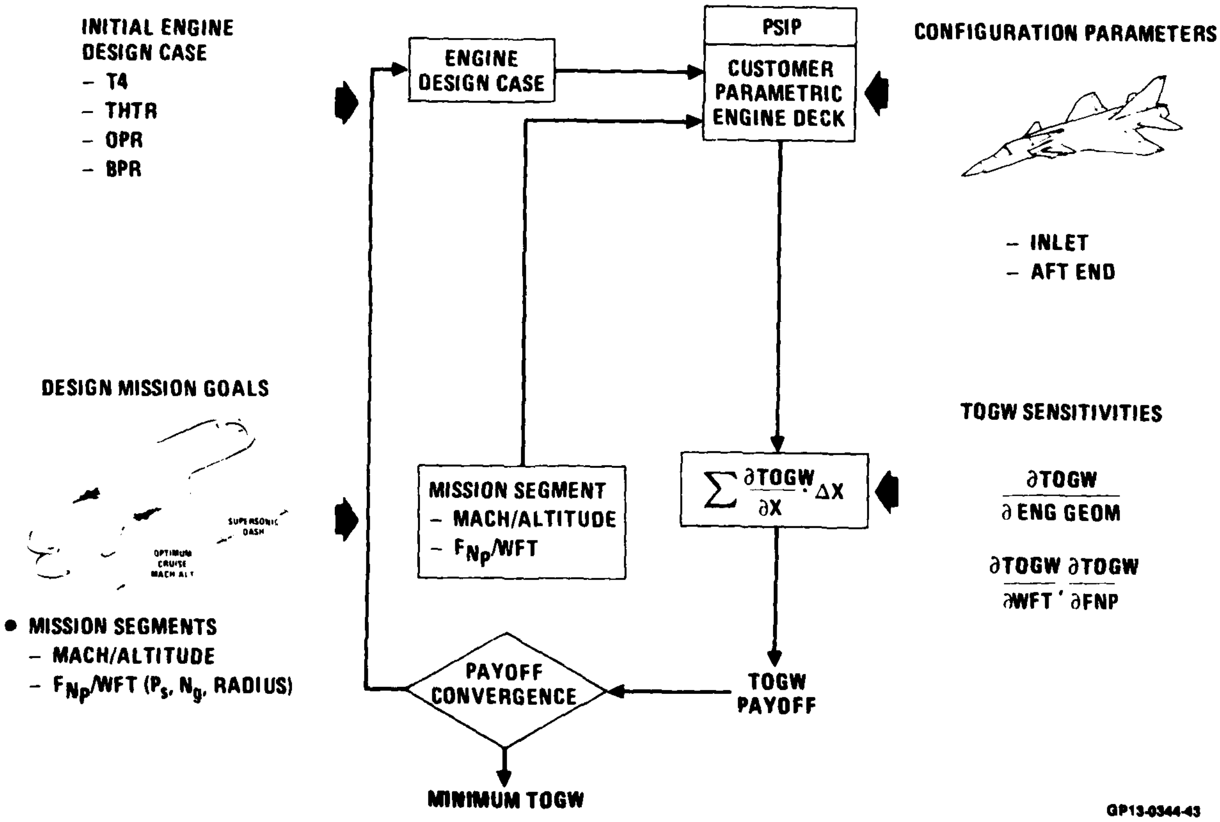
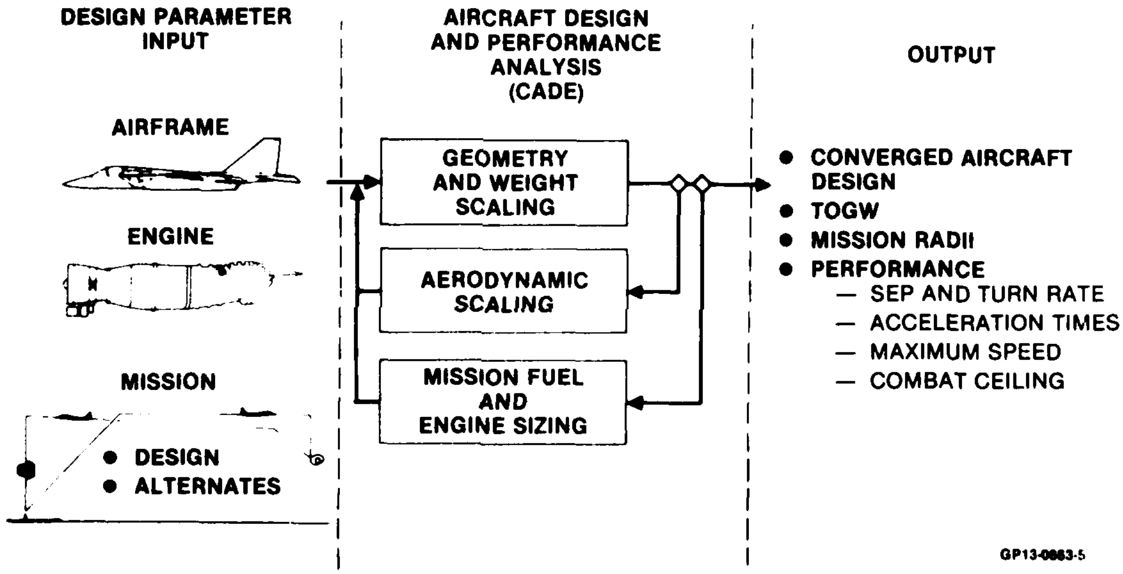


FIGURE 33
COMPUTERIZED AIRCRAFT DESIGN
EVALUATION PROCEDURE



The TOGW sensitivities computed for the variable sweep wing aircraft, shown in Figure 34, indicate that the interface parameters having the most significant effect on aircraft sizing are the thrust sizing points (maximum augmented thrust at .9 Mach, 30,000 feet and maximum dry thrust at .95 Mach, sea level), dash specific fuel consumption, and engine weight. These TOGW sensitivities were used to reoptimize the engine cycle.

FIGURE 34
TOGW SENSITIVITY TO INTERFACE PARAMETERS

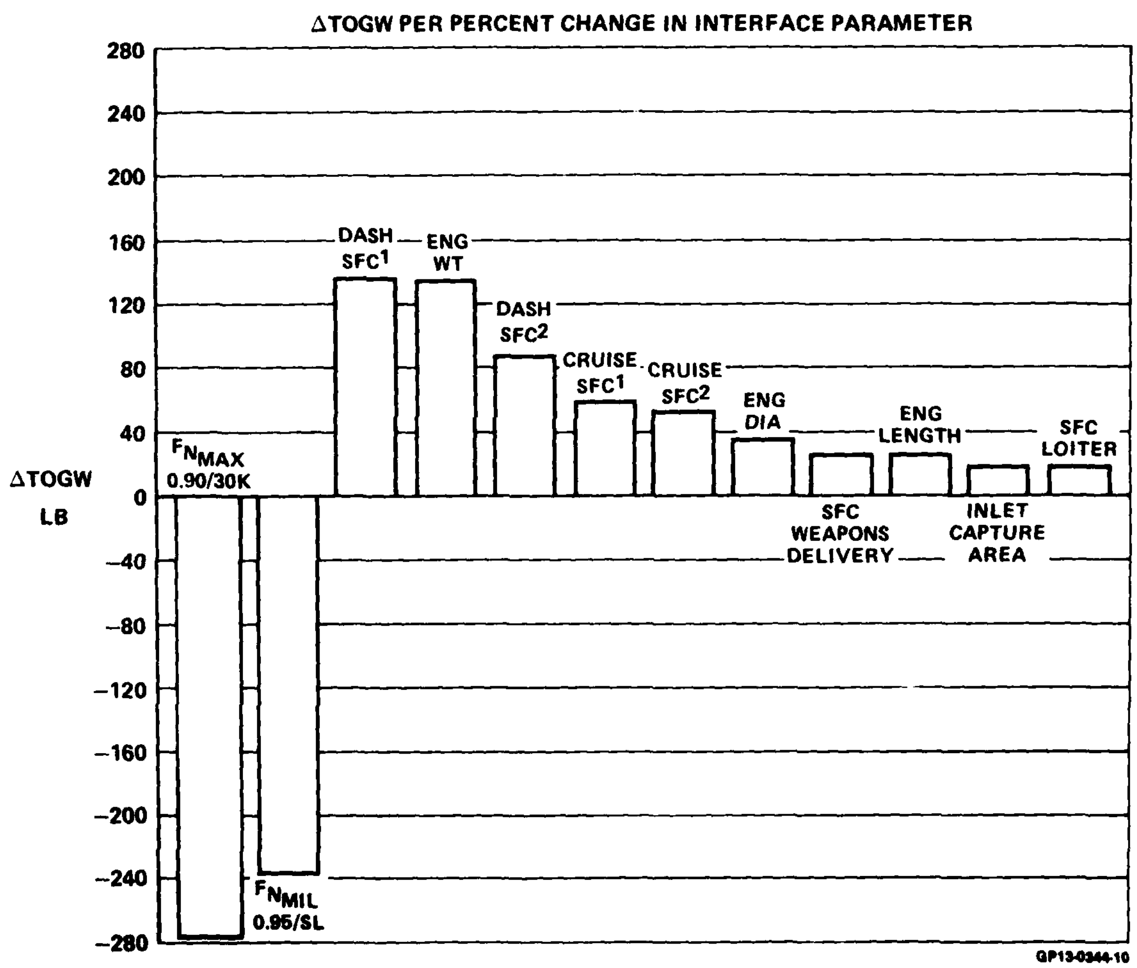
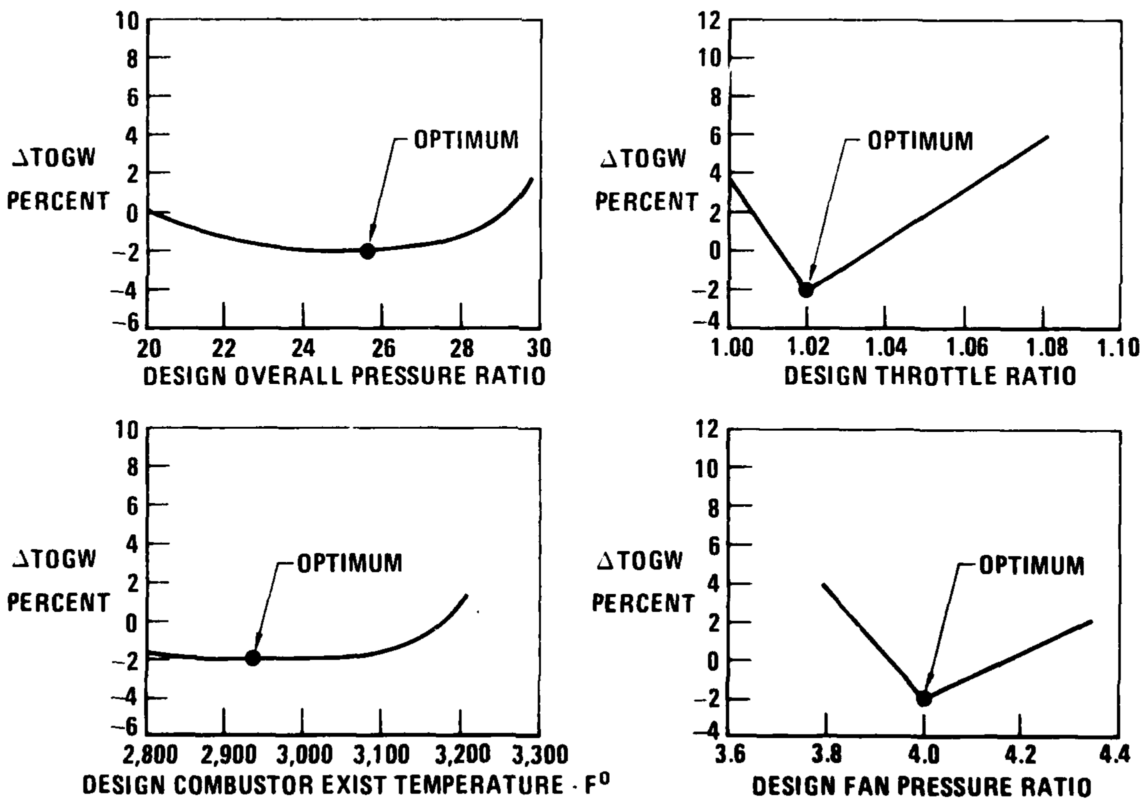


Figure 35 shows the parametric relationship between aircraft TOGW and the cycle variables optimized in this analysis. The parameters are combustor exit temperature (CET) overall pressure ratio (OPR), fan pressure ratio (FPR), and throttle ratio (THTR). The results indicated that TOGW was insensitive to variations in CET and OPR. FPR and THTR were found to have the most effect on TOGW. TOGW is sensitive to FPR and THTR due to the substantial effect of variations in these parameters on engine thrust at the sizing points, engine weight, and dash SFC. The engine cycle optimization results discussed above were computed based on aircraft sizing sensitivities developed for the low altitude design mission and the selected maneuverability requirements. Variations in these requirements may alter the cycle parameter optimization.

FIGURE 35
EFFECT OF CYCLE VARIABLES ON TOGW



Sizing criteria:

Mission	- Low altitude, transonic strike
Maneuverability	- 3.5 g @ Mach 0.9, 30,000 ft, max power
Excess P_S	- 50 FPS @ Mach 0.95, sea level, 1 g, int power
	100 FPS @ Mach 0.9, 30,000 ft, 1 g, max power

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The variable sweep wing aircraft was resized in CADE using the optimized engine cycle. The sizing results and the optimum engine cycle are summarized in Figure 36.

An aircraft sizing parametric was conducted to illustrate the effects of variations in takeoff thrust-to-weight ratio and wing loading on aircraft performance and sizing. These results are shown in Figure 37. The alternate mission performance for the high altitude mission was a fallout in this study.

FIGURE 36
REOPTIMIZED ENGINE/AIRFRAME

ENGINE CYCLE

OPR = 25.6
FPR = 4.0
CET = 2,933^{o}F
THROTTLE RATIO = 1.02
CORRECTED AIRFLOW = 130.7 LBM/SEC

AIRCRAFT SIZING

TOGW = 41,650 LB
T/W = 0.70
W/S = 134.8 LB/FT^2
FUEL FRACTION = 0.35

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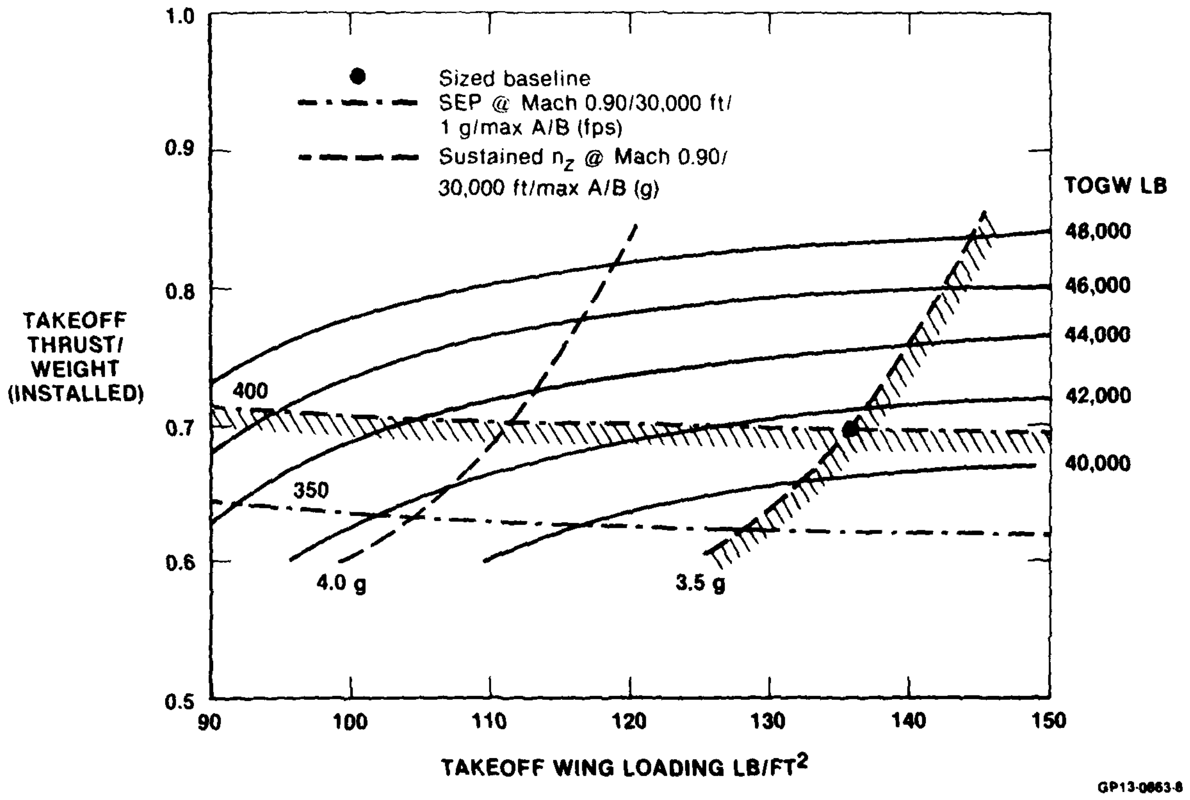
FIGURE 37
AIRCRAFT SIZING TRENDS
LOW ALTITUDE INTERDICTION MISSION



6. BASELINE ENGINE DUTY CYCLE

A baseline engine duty cycle was computed for the variable sweep wing aircraft to provide an initial assessment of the effect of advanced weapon systems on engine usage. In addition, comparisons were made with engine duty cycles computed for other advanced tactical strike aircraft to provide a preliminary indication of the effects of variations in aircraft design and performance on engine usage.

The peacetime missions developed for advanced tactical strike aircraft were input into the usage models along with the performance characteristics of the aircraft. Mach number, altitude and throttle time histories were computed and, using the COUNT program, throttle cycle and hot time accumulations were determined for each mission.

Figure 38 shows the results of this analysis. One Type I cycle is accumulated during each mission except the functional check flight (FCF). Two Type I cycles are accumulated in the FCF due to the engine shut down and air start performed as a matter of course in this mission.

FIGURE 38
ENGINE USAGE SUMMARY DATA

MISSION	FLIGHT TIME (MIN)	MISSION TIME (1) (MIN)	TYPE III CYCLES	HOT TIME (4) (MIN)	FREQUENCY (%)
HIGH ALTITUDE GROUND ATTACK	70.8	110.8	9(2) (6)(3)	34.8	10.0
LOW ALTITUDE GROUND ATTACK	65.3	105.3	21(17)	2.9	50.0
DEFENSIVE AIR COMBAT TRAINING	62.7	102.7	22(9)	14.6	18.0
INSTRUMENT/PROFICIENCY	94.7	134.7	14(6)	2.9	5.0
• WITH REFUELING	113.5	153.5	20(12)	4.4	7.0
TRANSITIONAL TRAINING					
• BASIC	88.3	128.3	29(14)	8.3	3.5
• ADVANCED	100.7	140.7	26(14)	7.7	3.5
FUNCTIONAL CHECK FLIGHT	75.0	115.0	7(5)	19.2	2.0
FERRY/CROSS COUNTY	146.1	186.1	2(0)	3.0	1.0
COMPOSITE MISSION	73.3	113.3	19.5(12.9)	9.0	

Notes:

(1) Mission time assumes 40 min for pre and post flight ground operation

(2) Type III cycle - Throttle movement from less than 43% intermediate to greater than 92% intermediate to less than 43% intermediate

(3) Type III cycle - Throttle movement from idle to intermediate to idle

(4) Hot time - Time at intermediate power or greater

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Two alternate definitions of Type III cycles were analyzed and are shown in Figure 38. The standard Type III cycle, historically used to characterize engine usage, represents a throttle movement from idle power to intermediate and back to idle. Damage assessments by P&WA for its advanced engine designs have indicated that certain partial cycles may cause nearly the same level of component deterioration as a full idle to intermediate transient. An alternate Type III cycle count is shown for throttle transients from 43% intermediate power or less to 92% intermediate power or greater and back to 43% intermediate power or less. These results show a significant variation in throttle cycles depending on the cycle definition.

The composite mission data, shown in Figure 38, was computed by applying the mission frequency weightings to the individual mission data. Using the composite mission, an engine duty cycle for 1,000 engine operating hours is presented in Figure 39.

Figures 38 and 39 indicate that engine duty cycles are substantially affected by (1) variations in peacetime mission frequencies, (2) variations in weapon delivery tactics resulting from advanced weapons technologies, (3) inclusion of partial throttle cycles.

FIGURE 39

BASELINE ENGINE DUTY CYCLE

1,000 Hr Engine Operation(1)

TYPE I CYCLES(2)	539
TYPE III CYCLES	10,315(3) (6,824)(4)
HOT TIME - HR	79.4

Notes:

(1) *No maintenance operation is included*

(2) Type I cycle - Engine off to intermediate to off

(3) Type III cycle - 43% intermediate to 92% intermediate

(4) Type III cycle - Idle to intermediate to idle

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Substantial variations in engine usage exist for different training missions. Missions such as the high altitude weapon delivery training and the functional check flight, involving periods of supersonic operation, accumulate significant amounts of hot time but few throttle cycles. It is anticipated that the frequencies for the High Altitude Attack mission will be relatively low due to the limited number of areas available for supersonic training. Air combat missions also contain substantial hot time accumulations. Other missions, such as the low altitude ground attack training and the transitional training missions contain many more throttle cycles but less hot time accumulation.

It is obvious from these results that variations in peacetime mission frequencies will have a significant effect on engine duty cycles. Such variations can occur as a result of a change in the combat role of the aircraft and base-to-base variations in mission frequencies (e.g. transitional training versus operational training bases).

Advanced weapon delivery tactics, such as high altitude weapon delivery, also have an effect on engine duty cycles.

Figures 38 and 39 indicate that a large number of partial cycles occur during peacetime mission, particularly in transitional training missions. Inclusion of partial cycles substantially alters the engine duty cycle. Therefore, those partial cycles which affect engine durability should be identified and included in the engine duty cycle.

7. EFFECT OF AIRCRAFT PERFORMANCE ON ENGINE USAGE

A preliminary analysis was conducted to identify the effects of variations in aircraft performance on engine usage. In this analysis, the duty cycle computed for the LUCID variable sweep wing CTOL aircraft was compared to duty cycles computed for two Advanced Tactical Attack Manned Systems (ATAMS) currently being investigated in the Advanced Technology Engine Studies (ATES), Reference 11. The ATAMS aircraft include a CTOL and a STOL configuration.

Usage variations for these aircraft are attributable to (1) different peacetime mission frequencies for the ATAMS CTOL, (2) thrust reverser operation during landing for the ATAMS STOL, and (3) performance differences for the three aircraft. Figure 40 compares the baseline duty cycles for the three aircraft and Figures 41 and 42 provide the CTOL and STOL engine usage data for individual missions. The peacetime mission frequencies for the ATAMS CTOL aircraft provide a heavier weighting for the high altitude attack which is the design mission for this aircraft. The peacetime mission profiles used to compute engine usage are the same for all three aircraft.

FIGURE 40
ENGINE DUTY CYCLE COMPARISON
1,000 HR ENGINE OPERATION(1)

	LUDIC BASELINE A/C	ATAMS CTOL	ATAMS STOL
THROTTLE CYCLES			
TYPE(2)	539	542	542
TYPE III(3)	6,824	4,938	7,222
TYPE III(4)	7,169	7,169	10,301
HOT TIME	79.4	72.6	78.8

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Notes:

(1) No maintenance operation is included
(2) Type I cycle = Engine off to intermediate to off
(3) Type III cycle = 43% intermediate to 92% intermediate to 43% intermediate
(4) Type III cycle = Idle to intermediate to idle

FIGURE 41
BASELINE ENGINE USAGE
ATAMS (CTOL) WEAPON SYSTEM

MISSION	FLIGHT TIME (MIN)	MISSION TIME(1) (MIN)	TYPE III CYCLES	HOT TIME(4) (MIN)	FREQUENCY (%)
HIGH ALTITUDE GROUND ATTACK	67.7	107.7	13(2) (8)(3)	26.4	10
LOW ALTITUDE GROUND ATTACK	65.2	105.2	22 (18)	2.65	50
DEFENSIVE AIR COMBAT TRAINING	59.4	99.4	16 (8)	12.9	18
INSTRUMENT/PROFICIENCY					
– WITHOUT REFUELING	98.3	138.3	15 (6)	9.6	5
– WITH REFUELING	117.6	157.6	21 (12)	11.45	7
TRANSITIONAL TRAINING					
– BASIC	90.2	130.2	29 (16)	16.1	3.5
– ADVANCED	102.7	142.7	23 (15)	10.8	3.5
FUNCTIONAL CHECK FLIGHT	75.2	115.2	6 (5)	17.7	2
FERRY/CROSS COUNTRY	147.8	187.8	4 (1)	3.5	1
COMPOSITE MISSION	72.9	112.9	19.4 (13.6)	8.9	100

Notes:

(1) Mission time assumes 40 minutes for pre- and post-flight operation

(2) Type III cycle = throttle movement from less than 43% intermediate to greater than 92% intermediate to less than 43% intermediate

(3) Type III cycle = throttle movement from idle to intermediate to idle

(4) Hot time = time at intermediate power or greater

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FIGURE 42
BASELINE ENGINE USAGE
ATAMS (STOL) WEAPON SYSTEM

MISSION	FLIGHT TIME (MIN)	MISSION TIME(1) (MIN)	TYPE III CYCLES	HOT TIME(4) (MIN)	FREQUENCY (%)
HIGH ALTITUDE GROUND ATTACK	67.7	107.7	13(2) (8)(3)	26.4	10
LOW ALTITUDE GROUND ATTACK	65.2	105.2	22 (18)	2.65	50
DEFENSIVE AIR COMBAT TRAINING	59.4	99.4	16 (8)	12.9	18
INSTRUMENT/PROFICIENCY					
– WITHOUT REFUELING	98.3	138.3	15 (6)	9.6	5
– WITH REFUELING	117.6	157.6	21 (12)	11.45	7
TRANSITIONAL TRAINING					
– BASIC	90.2	130.2	29 (16)	16.1	3.5
– ADVANCED	102.7	142.7	23 (15)	10.8	3.5
FUNCTIONAL CHECK FLIGHT	75.2	115.2	6 (5)	17.7	2
FERRY/CROSS COUNTRY	147.8	187.8	4 (1)	3.5	1
COMPOSITE MISSION	72.9	112.9	19.4 (13.6)	8.9	100

Notes:

(1) Mission time assumes 40 minutes for pre- and post-flight operation

(2) Type III cycle = throttle movement from less than 43% intermediate to greater than 92% intermediate to less than 43% intermediate

(3) Type III cycle = throttle movement from idle to intermediate to idle

(4) Hot time = time at intermediate power or greater

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In the engine duty cycles shown in Figure 43, the CTOL mission frequency variations and the STOL landing variations have been eliminated. The remaining usage differences reflect the performance differences for the three aircraft. Such differences are attributable primarily to variations in aircraft sizing parameters (e.g. thrust-to-weight ratio and wing loading) and engine cycle parameters (e.g. bypass ratio and throttle ratio).

FIGURE 43
CONFIGURATION IMPACT ON AIRCRAFT DUTY CYCLE

	LUCID BASELINE A/C	ATAMS CTOL(1)	ATAMS STOL(2)
THROTTLE CYCLES			
TYPE I	539	555 (3.0%)	542 (0.6%)
TYPE III(3)	6,824	6,093 (−10.7%)	6,676 (−2.2%)
TYPE III(4)	10,315	8,283 (−19.7%)	8,779 (−14.9%)
HOT TIME	79.4	57.1 (−22.3%)	66.0 (−13.4%)

Notes:

(1) ATAMS CTOL duty cycle adjusted to same mission frequency mix as ATAMS STOL and LUCID baseline aircraft

(2) ATAMS STOL duty cycle with no thrust reversing and no STOL landing effects

(3) Throttle movement from idle to intermediate to idle

(4) Throttle movement form 43% intermediate to 92% intermediate to 43% intermediate

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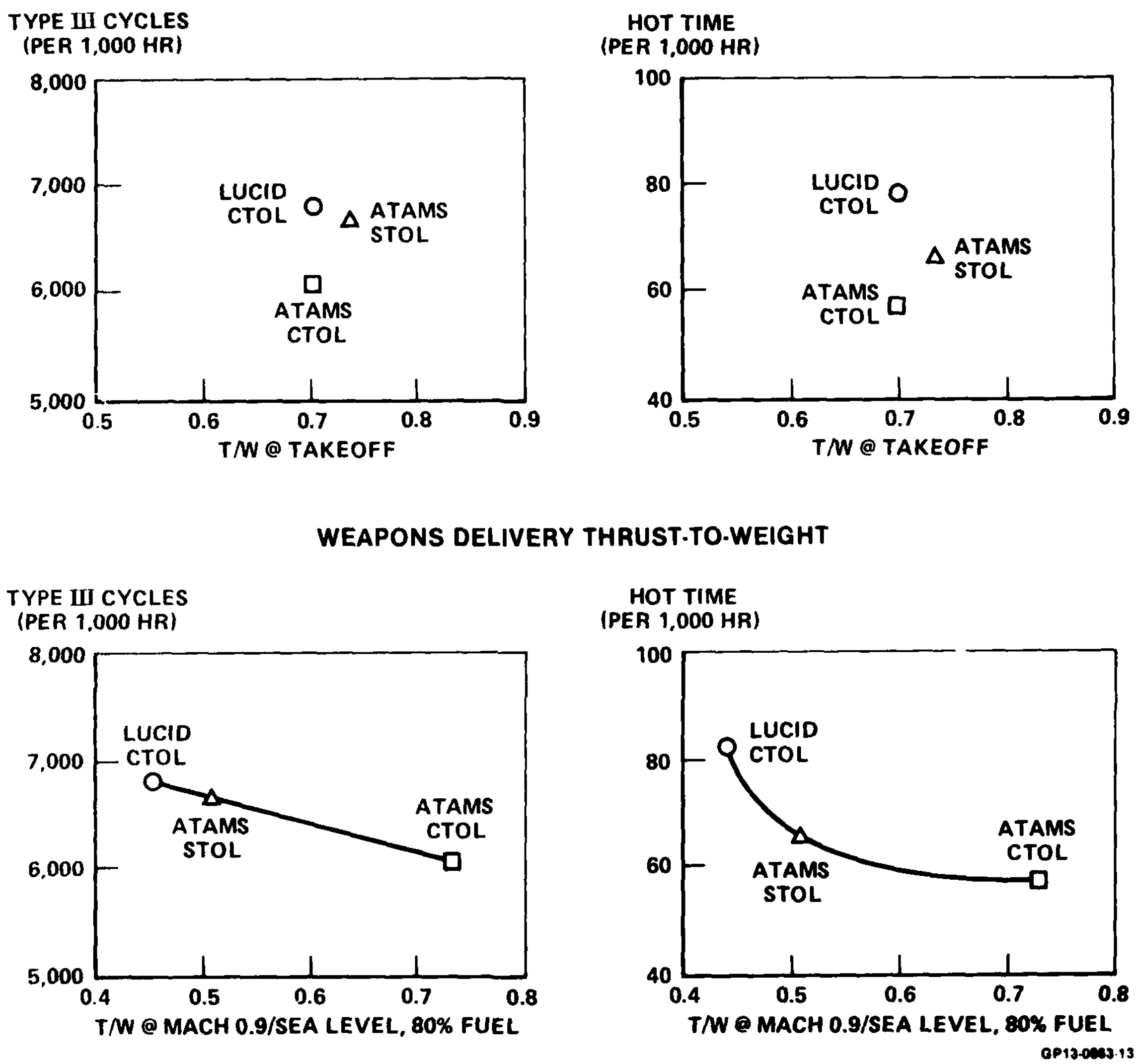
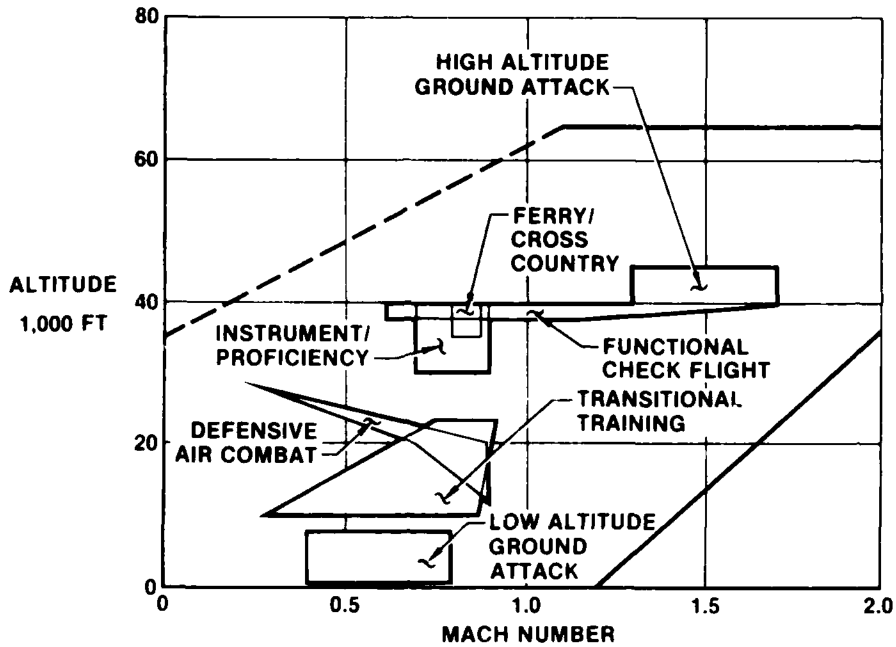
Engine usage sensitivities to variations in aircraft thrust-to-weight (T/W) and wing loading (W/S) were investigated. Figure 44 shows plots of Type III throttle cycles and hot time as a function of T/W. Thrust-to-weight ratios rated at takeoff (sea level, static, maximum afterburner) and at the low altitude weapon delivery condition (sea level, .9 Mach, intermediate power) were investigated. The results show a lack of correlation between engine usage and takeoff T/W but usage trends are apparent when T/W is evaluated at the weapon delivery condition.

FIGURE 44
EFFECT OF T/W ON TYPE III CYCLES AND HOT TIME



Engine usage does not correlate well with takeoff T/W because it does not represent the relative T/Ws of these aircraft at flight conditions and power settings where most of the training occurs and most of the throttle cycles and hot time are accumulated. Figure 45 illustrates the flight conditions where most of the engine usage is accumulated in each mission. Differences in engine parameters such as throttle ratio and augmentation ratio cause the relative T/W ratios to change with flight conditions and power settings.

FIGURE 45
PEACETIME MISSION FLIGHT CONDITIONS

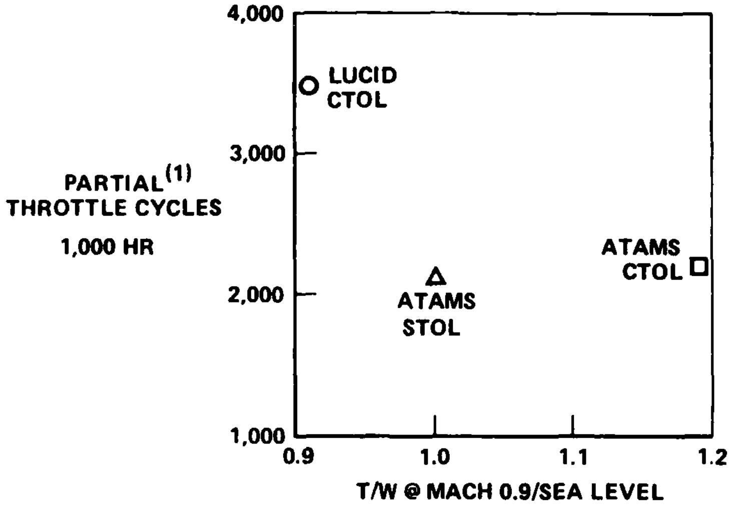


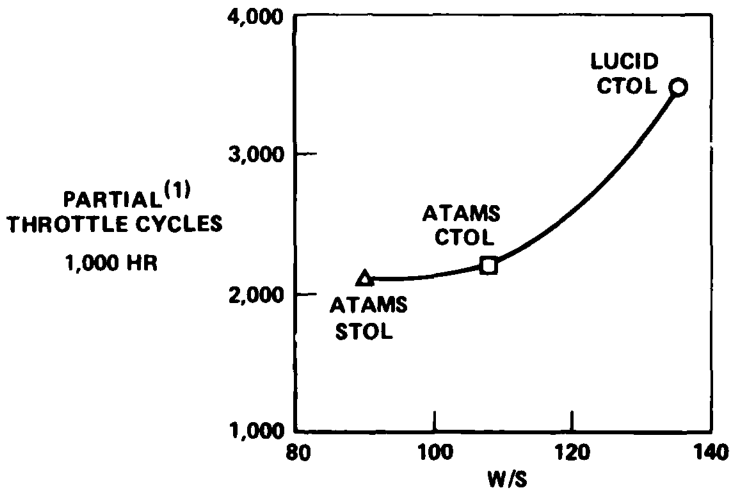
The correlation was improved significantly when throttle cycles and hot time were plotted as a function of T/W at the dash condition. At takeoff the T/W of the three aircraft are nearly constant. However, the T/W of the ATAMS CTOL aircraft is significantly higher in other mission segments due to the higher throttle ratio and lower bypass ratio of the engine cycle selected for this aircraft. This result indicates the importance of engine cycle parameters as well as rated T/W in determining engine usage.

The effect of wing loading on engine usage was also investigated. Little or no sensitivity to wing loading was identified for overall hot time and Type III cycle accumulations. However, it is anticipated that greater sensitivities will be demonstrated for individual mission segments, such as takeoff/climb and air combat training. These effects were not investigated in this preliminary analysis.

However, as indicated in Figure 46, wing loading may have an effect on partial cycle accumulations. Partial cycle counts were determined by subtracting the idle-intermediate-idle cycle count from the 48% intermediate - 92% intermediate - 48% intermediate cycle count. No usage trends are apparent with T/W, however, the correlation is improved when plotted versus W/S. Further analysis is required to substantiate this trend and to determine how W/S interacts with engine usage.

FIGURE 46
EFFECT OF T/W AND W/S ON PARTIAL CYCLES





(1) Partial cycles = 43% intermediate to 92% intermediate to 43% intermediate (excluding Type III cycles)

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The results presented above indicate general usage trends inferred from available data. However, these conclusions are limited because the three aircraft used in this analysis are different configurations with simultaneous variations in engine cycles and aircraft sizing parameters. A parametric study of engine usage sensitivity to changes in aircraft design parameters cannot be accomplished using the available data.

Variations in the combat role of the aircraft are also expected to have a significant effect on the usage sensitivities. Individual mission sensitivities vary significantly and changes in combat role which alter training mission frequencies, will also change the duty cycle sensitivity to engine and airframe design parameters.

Finally, the duty cycles presented in this analysis were all computed for standard day engine performance. Variations in ambient temperature may significantly affect aircraft performance and usage sensitivities, particularly for aircraft with different throttle ratios and, thus different thrust lapse rates with increasing ambient temperature.

8. CONCLUSIONS AND RECOMMENDATIONS

The engine usage prediction procedure developed in LUCID enables the effects of changes in advanced aircraft performance and training missions to be reflected in engine duty cycles. An analysis of engine usage for advanced tactical strike aircraft indicates that usage is significantly affected by variations in (1) weapon delivery techniques required for advanced air-to-surface missiles, (2) peacetime mission frequencies and (3) aircraft performance capabilities. The usage analysis also indicated that substantial accumulations of partial cycles may occur in peacetime missions.

Further analysis is required to quantify usage sensitivities to changes in engine and airframe design parameters and variations in peacetime missions and frequencies. This analysis would identify the key mission and design parameters which determine engine duty cycles for advanced fighters. Partial cycles affecting engine durability should be identified and the relative weighting for partial cycles in engine duty cycles should be determined. In addition, further analysis is needed to determine (1) the effects of usage variations or engine life and (2) the effects of engine life variations on aircraft performance and life cycle cost.

Finally, additional effort is needed to refine and further validate the procedures developed in LUCID. Initial assessments of the procedure have indicated that accurate duty cycle projections can be made for fighter aircraft. Model predictions have agreed well with actual usage rates for the F-15/F100 recorded by Events History Records at Eglin, Luke and Bitburg. However, further analysis is needed to verify, on a mission segment-by-segment basis, that the model accurately simulates engine usage during individual mission segments and maneuvers. Accurate simulations of the maneuvers performed in individual training segments are essential in projecting engine duty cycles for advanced fighter engines.

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(6) Dowling, N.E., "Fatigue Failure Predictions for Complicated Stress-Strain Histories," Journal of Materials, JMLSA, Vol. 7, No. 1, March 1972, pp. 71-87.

(7) USAF Tactical Air Command, "F-4 Aircraft Mission Profile Study", 1975.

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Appendix A

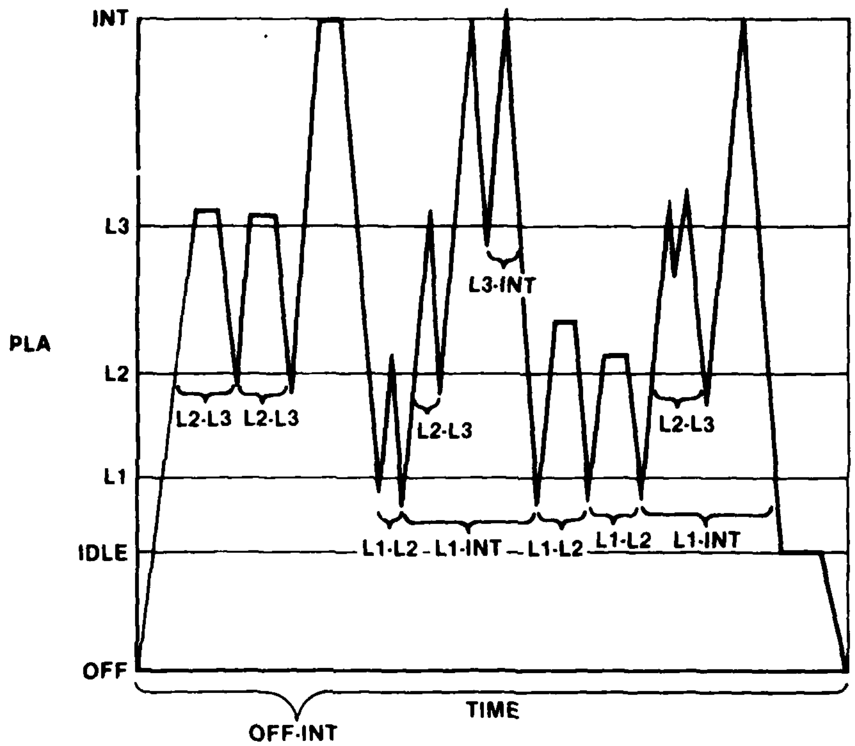
Cycle Counting Procedure

A program was developed to count throttle cycles and hot time accumulations for the mission time histories computed by the usage models. The cycle counting logic in the COUNT program uses the Rainflow Cycle Counting method described in Reference 6.

Throttle cycles are defined in terms of a starting point (a low gate) and an ending point (a high gate). The COUNT program analyzes each cycle in the mission time history to determine the cycle starting and ending points and to determine whether the cycle forms part of a more severe cycle. Cycle types are then determined in order of severity. Figure A-1 provides a sample throttle time history and summarizes the cycle count.

Hot time is determined by counting the mission time spent at or above intermediate power.

FIGURE A-1
THROTTLE CYCLE COUNTING PROCEDURE



CYCLE SUMMARY

		INITIAL PLA				
		OFF	IDLE	L1	L2	L3
PEAK PLA	INT	1	0	2	0	1
	L3		0	0	4	
	L2		0	3		
	L1		0			

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Appendix B

Peacetime Mission Profiles

The usage prediction procedure developed by MCAIR requires detailed descriptions of peacetime missions. In order to simulate training missions in the usage models, the flight path and training maneuvers performed in each mission segment must be defined.

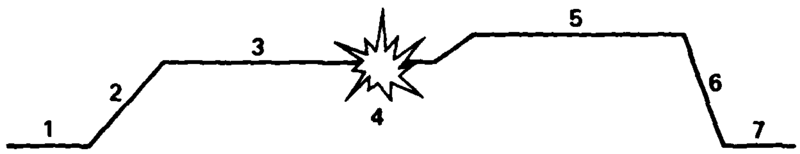
In LUCID an advanced tactical strike aircraft was investigated. The mission inputs developed for the LUCID study aircraft are described in this Appendix. The mission descri tions were developed by reviewing mission data for current data nd by projecting changes in the flight profiles and training ma rs due to advanced weapon system capabilities.

The missions selected for advanced tactical strike aircraft include both transitional training and operational training. The transitional training mission defined for this study were based on missions flown at Luke Air Force Base (AFB) and the operational missions were based on Eglin AFB. Nine peacetime missions were selected and the mission profiles are discussed below.

High Altitude Ground Attack - The flight profile for the high altitude attack mission is shown in Figure B-1. This mission consists of a standard takeoff out of Eglin AFB followed by a rejoin with a lead aircraft. The aircraft then climbs to an altitude of 40,000 feet and an airspeed of 450 knots to cruise approximately 35 nautical miles over the gulf to the W-151 training area where supersonic flight maneuvers can be conducted. Three simulated weapon deliveries are conducted along with evasive maneuvers at speeds and altitudes ranging from Mach 1.4 and 40,000 feet to Mach 1.7 and 50,000 feet. The weapon delivery patterns are shown in Figure B-2. The number of weapon deliveries was limited by fuel availability. After cruising back to the base, two touch-and-go landings are performed prior to landing. The specific maneuvers performed in the mission are summarized in Table B-1.

Low Altitude Ground Attack - The flight profile for the low altitude attack mission is shown in Figure B-3. The altitudes and airspeed during takeoff, cruises and landing are based on Eglin operating procedures and local FAA constraints. The training segments include a 180 nautical mile terrain following segment flown at 580 knots (Mach number = .88) and 150 feet above ground level. The terrain following segment in the design mission is flown at 620 knots (Mach number = .95). However, it is anticipated that training missions will normally be flown at lower speeds due to safety considerations and to maximize the structural life of the airframe.

FIGURE B-1
HIGH-ALTITUDE GROUND ATTACK TRAINING MISSION



MISSION SEGMENT	ALTITUDE (k - FT)	MACH NUMBER	DISTANCE (NM)
1 SHORT TAKEOFF/REJOIN	0.1 - 0.5	–	–
2 CLIMB	0.5 - 40	0.80	–
3 CRUISE	40	0.84	35
4 GROUND ATTACK (3 PASSES)	40 - 45	1.4 - 1.7	–
5 CRUISE	45	0.90	18
6 DESCENT	45 - 2	–	–
7 LANDING	SL	–	–

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FIGURE B-2
HIGH ALITITUDE WEAPON DELIVERIES

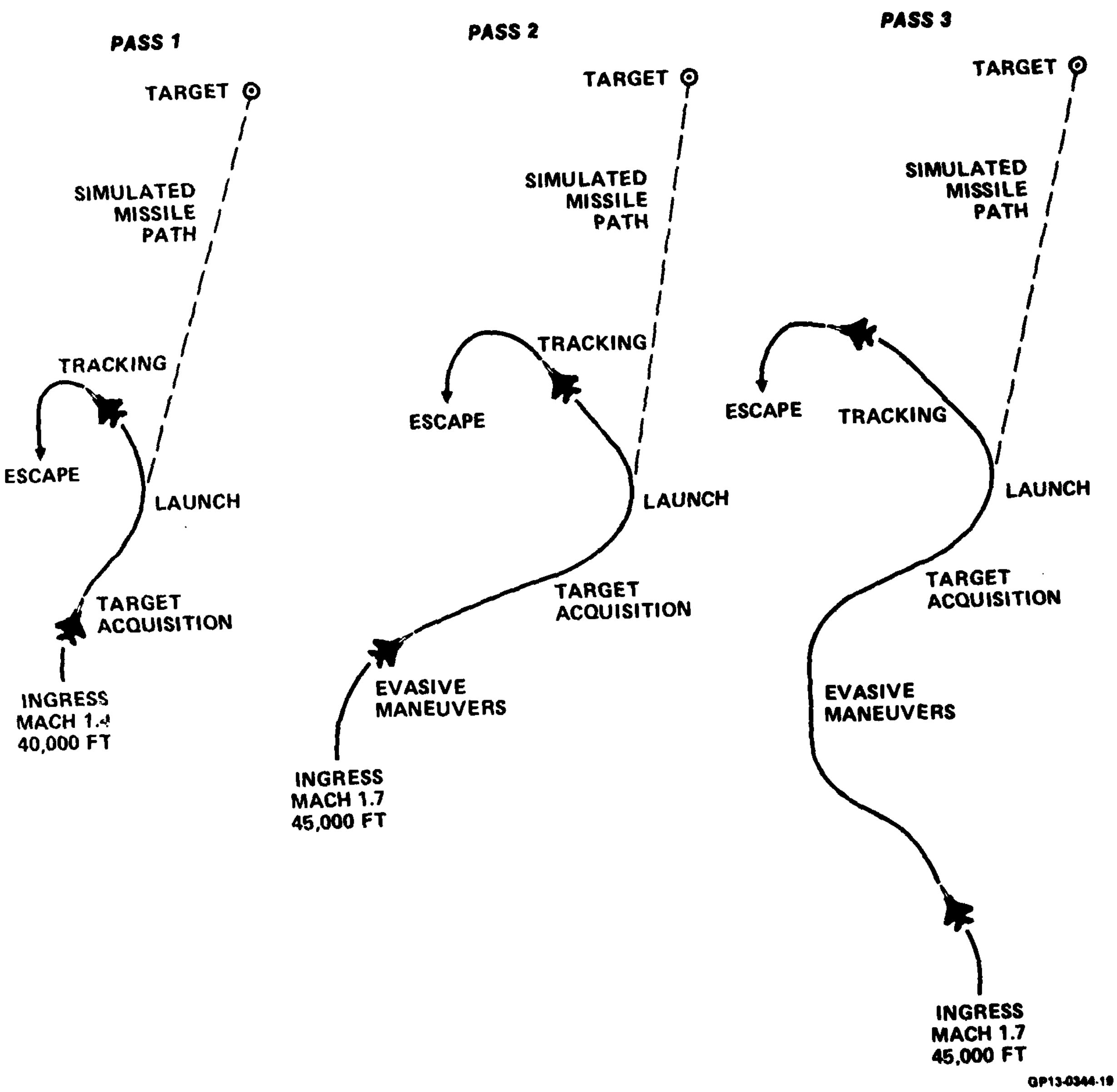
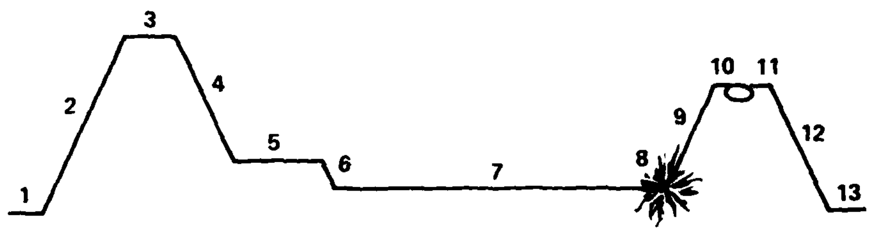


FIGURE B-3
LOW-ALTITUDE GROUND ATTACK TRAINING MISSION



	MISSION SEGMENT	ALTITUDE (k - FT)	MACH NUMBER	DISTANCE (NM)
1	TAKEOFF/REJOIN	0.1 - 0.5	–	–
2	CLIMB	0.5 - 7	0.66	–
3	CRUISE	7	0.66	18
4	DESCENT	7 - 2	0.63	–
5	CRUISE	2	0.57	36
6	DESCENT	2 - 0.5	0.88	–
7	LOW LEVEL DASH (150 FT TERRAIN CLEARANCE)	–	0.88	165
8	GROUND ATTACK	0.5 - 8	0.40 - 0.76	–
9	CLIMB	0.5 - 8	0.44	–
10	LOITER (5 MIN)	5	0.44	–
11	CRUISE	5	0.66	18
12	DESCENT	5 - 0.1	–	–
13	LANDING	0.1	0	–

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The terrain features selected for the terrain following segment are representative of the terrain profiles over which pilots train at USAF air bases. Terrain features at USAF bases were reviewed and categorized as either flat, rolling, hilly or mountainous based on the criteria shown in Figure B-4. Figure B-5 summarizes the flight hour accumulations in each type of terrain for F-4 aircraft. These frequency weightings were used to construct a representative terrain profile for the low altitude attack mission.

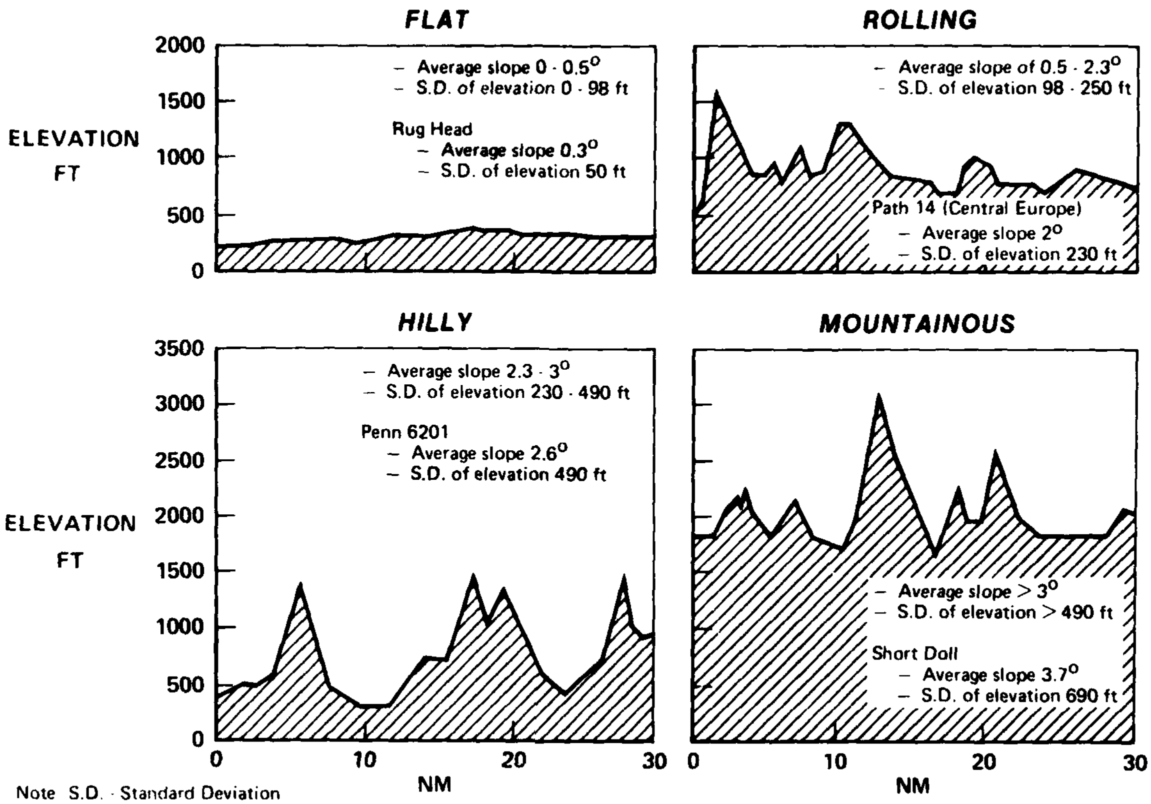
The low level segment is terminated at the training range and the weapon delivery training segment is initiated with a pop-up maneuver followed by simulated weapon deliveries including level and low angle deliveries, high angle dives, nuclear deliveries and strafing runs. Figure B-6 illustrates the pop-up weapon deliveries and "box patterns" which are flown at controlled ranges in ground attack training missions. Due to safety considerations, the airspeeds, altitudes and flight path are carefully controlled. Data available for F-4, B-7 and F-111 weapon deliveries were reviewed to identify flight paths flown in ground attack training.

A total of ten weapon deliveries lasting approximately 35 minutes were simulated. The number of weapon deliveries were limited, in this mission, by time constraints rather than by fuel availability. Range scheduling considerations generally limit time over target to approximately 30-40 minutes for a flight of aircraft. After the weapon deliveries, the aircraft rejoin, cruise back to base and land. No touch and go landings are included in this mission because pilot fatigue is expected to be high due to the high "g" maneuvering conducted for extensive period of time in the terrain following and ground attack mission segments. The specific set of maneuvers performed in this mission are summarized in Table B-2.

Defensive Air Combat Training - The flight profile for the Defensive Air Combat mission is shown in Figure B-7. This mission consists of a standard takeoff out of Eglin AFB followed by a rejoin with a lead aircraft. The aircraft then climbs to an altitude of 20,000 feet and an airspeed of 400 knots to cruise approximately 40 nautical miles to the W-151 training area.

At the training range, air combat engagements are flown. Engagement times of approximately three minutes and set up times between engagements of approximately four minutes were selected based on current air combat training data. Air combat maneuvers are practiced against similar aircraft (1V1 and 2V1) or against a dissimilar threat (1V1 and 2V1). The threat aircraft used in the simulation was an F-15. The number of air combat engagements performed in a mission are limited by fuel availability. Ninety-two air combat engagements and starting conditions were simulated

FIGURE B-4
TERRAIN CLASSIFICATION



Note S.D. - Standard Deviation

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FIGURE B-5
LOW LEVEL TRAINING DISTRIBUTION
F-4 Training Missions

TERRAIN TYPE	EXAMPLE OF BASE	CUMULATIVE F-4* FLIGHT HOUR BREAKDOWN (%)
FLAT	EGLIN, HOMESTEAD	44.7
ROLLING	SPANGDAHLEM	17.0
HILLY	GEORGE, LUKE	29.9
MOUNTAINOUS	NELLIS	9.4
	TOTAL	100.0

*MCAIR product support data

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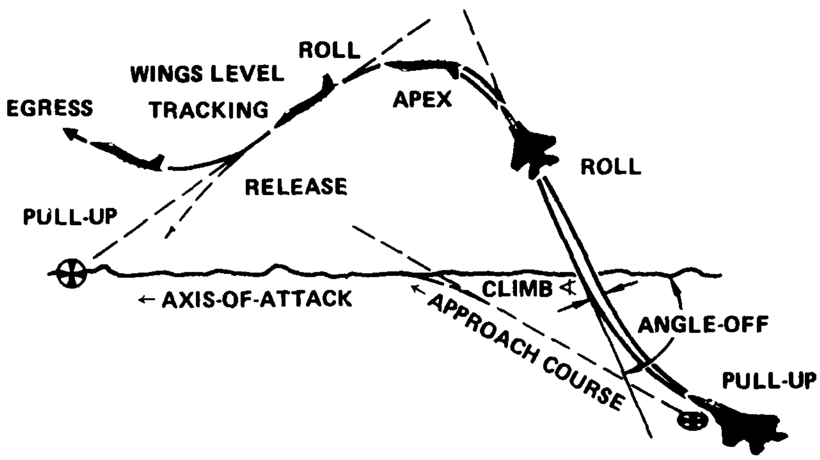
FIGURE B-6
LOW ALTITUDE GROUND ATTACK WEAPON DELIVERIES

TYPICAL ANGLE OFF POPUP MANEUVER



TYPICAL AIR-TO-GROUND BOX PATTERN 30° TRAINING PATTERN

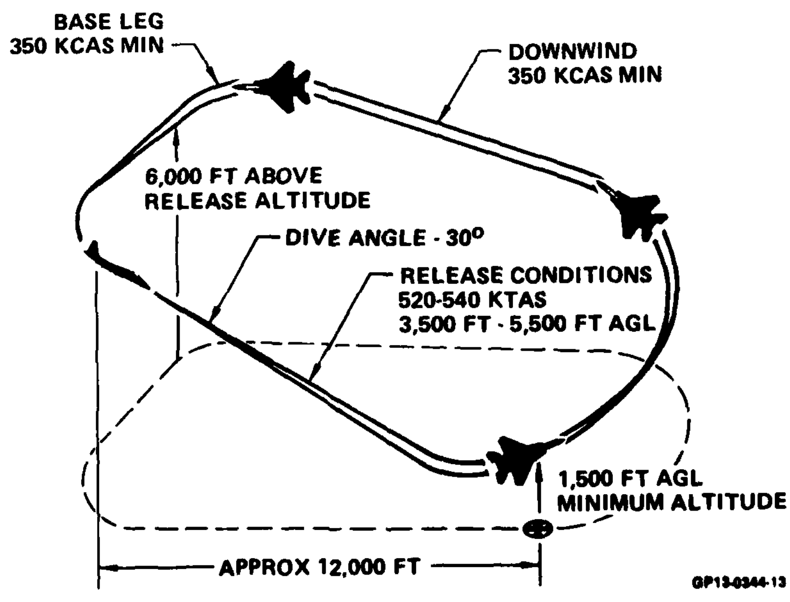
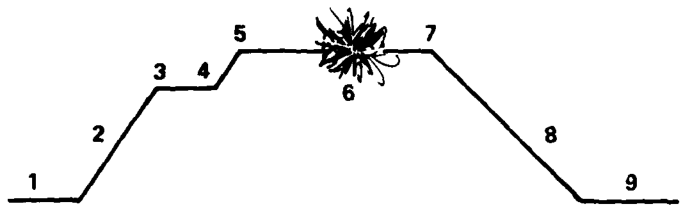


FIGURE B-7
DEFENSIVE AIR COMBAT TRAINING MISSION



MISSION SEGMENT	ALTITUDE (k - FT)	MACH NUMBER	DISTANCE (NM)
1 TAKEOFF	0.1	–	–
2 CLIMB	0.1 - 15	0.48	–
3 REJOIN	15	0.80	35
4 CLIMB	15 - 20	0.74	–
5 CRUISE	20	0.75	40
6 AIR COMBAT	–	–	–
7 CRUISE	20	0.75	25
8 DESCENT	20 - 0.1	–	–
9 LANDING	0.1	–	–

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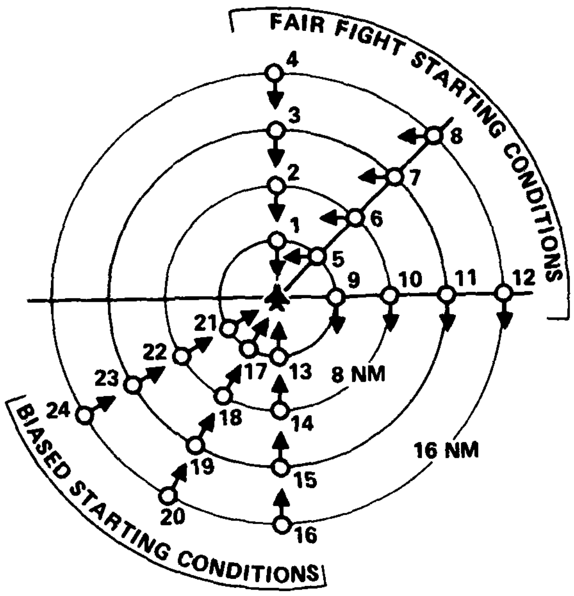
in MOABS and are summarized in Figure B-8. The other mission segments including takeoff, climb, cruise, descent and landings were simulated in GETUP. The specific set of maneuvers performed in this mission are summarized in Table B-3.

Instrument/Proficiency Training - The flight profiles for this mission are shown in Figures B-9 and B-10. The instrument/proficiency mission initiates with a standard takeoff out of Eglin AFB. The training maneuvers performed in this mission include aerial refueling for 50% of the missions, training in the use of the synthetic aperature radar (SAR) to acquire and identify targets, instrument approaches, and touch and go landings. In the aerial refueling segment, six rejoins with a tanker aircraft flying at 31,000 feet and 300 knots are performed. Fuel is transferred during the last tanker rejoin. The avionics training consists of flying at 40,000 feet and 450 knots and using the SAR to locate realistic targets such as bridges, trucks, power plants and roads. The instrument approaches are conducted at Montgomery, Alabama. The specific set of maneuvers performed in this mission are summarized in Table B-4 and B-5.

FIGURE B-8
STARTING CONDITIONS AND FORCE RATIOS FOR ACT AND DACT

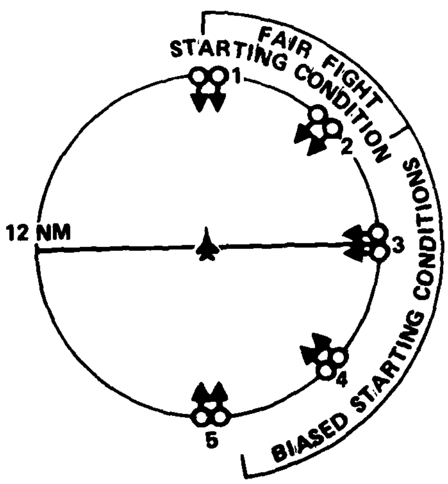
1 vs 1

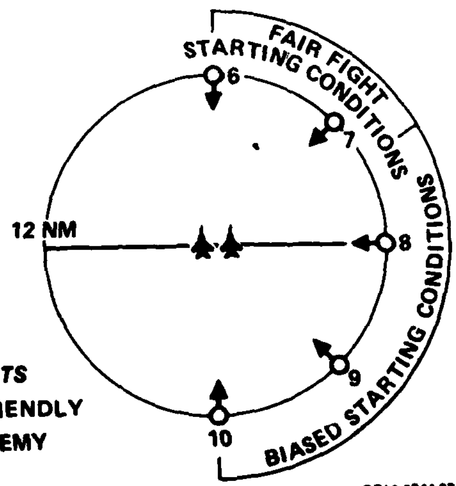


36 ENGAGEMENTS

- 12 BIASED FRIENDLY
- 12 BIASED ENEMY
- 12 NEUTRAL

1 vs 2





10 ENGAGEMENTS

- 3 BIASED FRIENDLY
- 3 BIASED ENEMY
- 4 NEUTRAL

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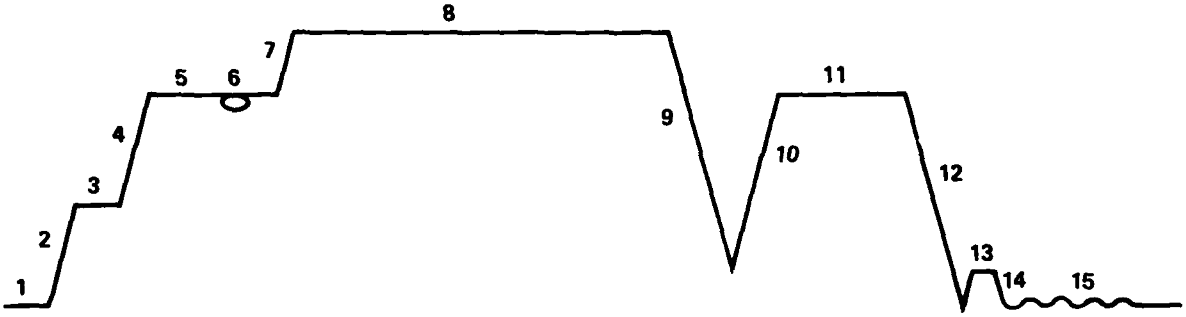
FIGURE B-9
INTRUMENT/PROFICIENCY TRAINING MISSION WITH AERIAL REFUELING



MISSION SEGMENT	ALTITUDE (k - FT)	MACH NUMBER	DISTANCE (NM)
1 TAKEOFF	0.1	–	–
2 CLIMB	0.1 - 15	0.55	–
3 CRUISE	15	0.55	20
4 CLIMB	15 - 31	0.60	–
5 CRUISE	31	0.92	60
6 AERIAL REFUELING (5 REJOINS)	31	0.67	–
7 CLIMB	31 - 40	0.76	–
8 CRUISE	40	0.91	175
9 DESCENT/MISSED APPROACH	40 - 5	–	–
10 CLIMB	5 - 31	0.53	–
11 CRUISE	31	0.64	60
12 DESCENT/MISSED APPROACH	31 - 5	–	–
13 CRUISE	5	0.46	10
14 DESCENT	5 - 0.1	–	–
15 LANDING PRACTICE (5 TOUCH AND GOES)	0.1	–	–

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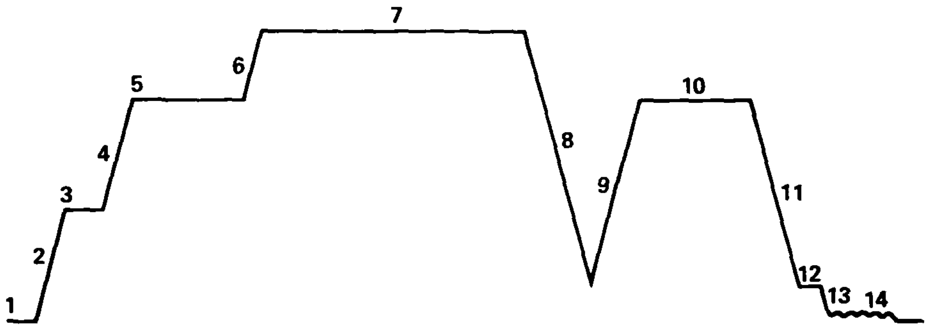
FIGURE B-10
INSTRUMENT/PROFICIENCY TRAINING MISSION WITHOUT AERIAL REFUELING



MISSION SEGMENT	ALTITUDE (k - FT)	MACH NUMBER	DISTANCE (NM)
1 TAKEOFF	0.1	–	–
2 CLIMB	0.1 - 15	0.55	–
3 CRUISE	15	0.55	20
4 CLIMB	15 - 31	0.60	–
5 CRUISE	31	0.92	60
6 CLIMB	31 - 40	0.76	–
7 CRUISE	40	0.91	140
8 DESCENT/MISSED APPROACH	40 - 5	–	–
9 CLIMB	5 - 31	0.53	–
10 CRUISE	31	0.64	60
11 DESCENT/MISSED APPROACH	31 - 5	–	–
12 CRUISE	5	0.46	10
13 DESCENT	5 - 0.1	–	–
14 LANDING PRACTICE (5 TOUCH AND GOES)	0.1	–	–

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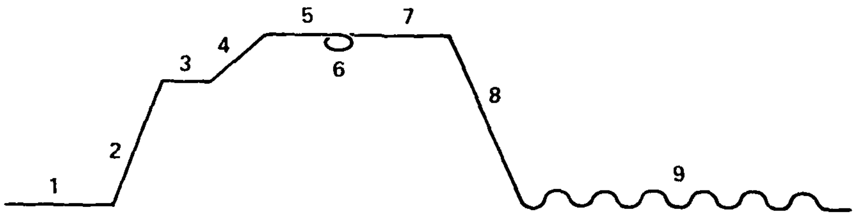
Transitional Training - The flight profiles for these missions are shown in Figures B-11 and B-12. Two transitional training missions were simulated - a basic mission and an advanced mission. The basic mission starts with a takeoff/climb profile to 23,000 feet as restricted by FAA procedures at Luke AFB. The aircraft cruises 30 nautical miles at 350 knots airspeed to the R-230A military operating area. At the training range, familiarization with the aircraft throughout the flight envelope is initiated. First, aircraft handling characteristics at slow airspeeds down to 170 KTAS are investigated for 30 minutes in a series of turns, descents, and climbs. Next, formation flying maneuvers including pitchouts and rejoins are practiced for 10 minutes followed by aerobatic maneuver training between 10,000 and 15,000 ft. On landing, six touch and goes are performed to simulate landing proficiency training. The advanced mission starts with the same takeoff/climb profile and cruise segment as the basic mission. The training maneuvers performed in this mission include approximately 30 minutes of formation flying maneuver with pitchouts and rejoins, and basic fighter maneuvers such as pitch backs and Immelmans. The aircraft cruises to Luke Auxiliary Field where two instrument approaches are made followed by a cruise back to Luke AFB where an additional two touch and goes and a landing are performed. The specific set of maneuvers performed in these missions are summarized in Table B-6 and B-7.

FIGURE B-11
TRANSITIONAL TRAINING MISSION
Basic (Luke No. 1)



MISSION SEGMENT	ALTITUDE (k - FT)	MACH NUMBER	DISTANCE (NM)
1 TAKEOFF/REJOIN	1.1	–	–
2 CLIMB	1.1 - 16	0.68	–
3 CRUISE	16	0.75	14
4 CLIMB	16 - 23	0.74	–
5 CRUISE	23	0.78	17
6 TRAINING	–	–	–
7 CRUISE	23	0.78	30
8 DESCENT	23 - 1.1	–	–
9 LANDING PRACTICE (6 TOUCH AND GOES)	1.1	–	–

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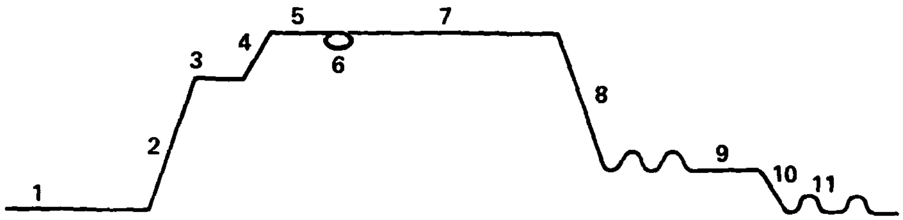
FIGURE B-12
TRANSITIONAL TRAINING MISSION
Advanced (Luke No. 2)



MISSION SEGMENT	ALTITUDE (k - FT)	MACH NUMBER	DISTANCE (NM)
1 TAKEOFF/REJOIN	1.1	–	–
2 CLIMB	1.1 - 16	0.68	–
3 CRUISE	16	0.75	14
4 CLIMB	16 - 23	0.74	–
5 CRUISE	23	0.78	17
6 TRAINING	–	–	–
7 CRUISE	23	0.78	50
8 DESCENT/MISSED APPROACH (2)	23 - 5	–	–
9 CRUISE	5	0.46	25
10 DESCENT	5 - 1.1	–	–
11 LANDING PRACTICE (2 TOUCH AND GOES)	1.1	–	–

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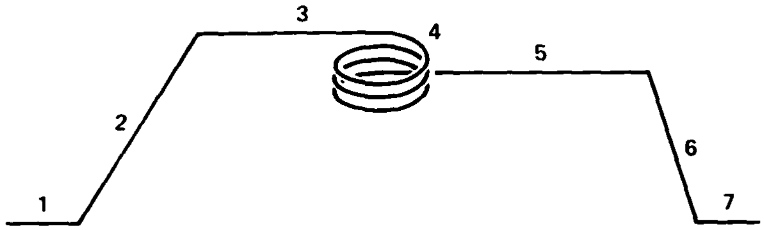
Functional Check Flight - The flight profile for this mission is shown in Figure B-13. This mission starts with a standard takeoff from Eglin AFB and a climb to 40,000 ft. Then, the aircraft cruises approximately 50 nautical miles at 450 knots true airspeed to the W-151 training area. At the training range, aircraft system checks are performed including a 1.6 Mach supersonic dash, engine airstarts, and throttle snaps/chops. The specific set of maneuvers performed in this mission are summarized in Table B-8.

Ferry/Cross Country - The flight profile for this mission is shown in Figure B-14. This mission consists of a takeoff from Eglin AFB, a cruise at 40,000 feet for 50 minutes, a cruise at 45,000 feet for 70 minutes and a straight in landing. The step climb from 40,000 to 45,000 feet is performed to maximize range. The specific maneuvers in this mission are summarized in Table B-9.

FIGURE B-13
FUNCTIONAL CHECK FLIGHT MISSION



MISSION SEGMENT	ALTITUDE (k - FT)	MACH NUMBER	DISTANCE (NM)
1 TAKEOFF	0.1	–	–
2 CLIMB	0.1 - 40	0.62	–
3 CRUISE	40	0.85	50
4 SYSTEM CHECKS	–	–	–
5 CRUISE	24	0.74	80
6 DESCENT	24 - 0.1	–	–
7 LANDING	0.1	–	–

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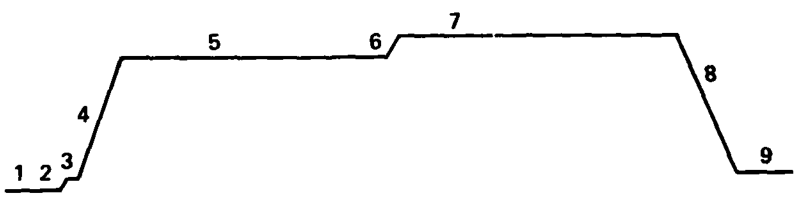
FIGURE B-14
FERRY/CROSS COUNTRY MISSION



MISSION SEGMENT	ALTITUDE (k - FT)	MACH NUMBER	DISTANCE (NM)
1 TAKEOFF	0.1	–	–
2 CLIMB	0.1 - 1.5	0.40	–
3 CRUISE/REJOIN	1.5	0.70	20
4 CLIMB	1.5 - 35	0.80	–
5 CRUISE	35	0.80	320
6 CLIMB	35 - 40	0.80	–
7 CRUISE	40	0.85	590
8 DESCENT	40 - 0.1	–	–
9 LANDING	0.1	–	–

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TABLE B-1

HIGH ALTITUDE GROUND ATTACK MISSION

SEGMENT DESCRIPTION	ENDING CONDITIONS AIRSPEED (KTAS)	ALTITUDE (FT)	HEADING (DEG)	RANGE (NM)	MANEUVER CONSTRAINTS LOAD FACTOR (G'S)	CLIMB ANG (DEG)	A/B OPERATION
1. Takeoff	350	1500	170		2.0	-	X
2. Rejoin	425	1500	170	2	-	-	
3. Climb/Turn	480	15000	167	12	3.0	-	
4. Climb	520	40000	167	35	2.0	-	
5. Acceleration	550	40000	167	6	2.0	-	
6. Turn	550	40000	253	18	2.0	-	
7. Weapon Delivery 1							
- Acceleration	800	40000	253	20	-	-	X
- Cruise	800	40000	253	10	-	-	X
- Turn	800	40000	238	3	3.5	-	X
- Cruise	800	40000	238	5	-	-	X
- Turn	800	40000	268	3	3.5	-	X
- Cruise	800	40000	268	5	-	-	X
- Sustained Turn	550	40000	73	-	-	-	X

(TABLE B-1) (Continued)

HIGH ALTITUDE GROUND ATTACK MISSION

SEGMENT DESCRIPTION	ENDING CONDITIONS AIRSPEED (KTAS)	ALTITUDE (FT)	HEADING (DEG)	RANGE (NM)	MANEUVER CONSTRAINTS LOAD FACTOR (G'S)	CLIMB ANG (DEG)	A/B OPERATION
8. Setup							
- Cruise	550	40000	73	50	-	-	
- Turn	550	40000	253	10	1.5	-	
- Climb	550	45000	253	25	3.0	-	X
9. Weapon Delivery 2							
- Acceleration	975	45000	253	25	-	-	X
- Turn	975	45000	268	2	3.5	-	X
- Cruise	975	45000	268	4	-	-	X
- Turn	975	45000	283	2	3.5	-	X
- Cruise	975	45000	283	4	-	-	X
- Turn	975	45000	253	2	3.0	-	X
- Cruise	975	45000	253	4	-	-	X
- Turn	975	45000	203	2	3.5	-	X
- Cruise	975	45000	203	6	-	-	X
- Turn	975	45000	293	3	4.0	-	X

(TABLE B-1) (Continued)

HIGH ALTITUDE GROUND ATTACK MISSION

SEGMENT DESCRIPTION	ENDING CONDITIONS AIRSPEED (KTAS)	ALTITUDE (FT)	HEADING (DEG)	RANGE (NM)	MANEUVER CONSTRAINTS LOAD FACTOR (G'S)	CLIMB ANG (DEG)	A/B OPERATION
- Cruise	975	45000	293	3	-	-	X
- Sustained Turn	550	45000	73	-	-	-	X
10. Setup							
- Cruise	490	45000	73	31	-	-	
- Acceleration	550	45000	73	30	-	-	
- Turn	550	45000	253	10	1.8	-	
- Cruise	550	45000	253	5	-	-	
11. Weapon Delivery 3							
- Acceleration	975	45000	253	25	-	-	
- Turn	975	45000	268	2	3.5	-	X
- Cruise	975	45000	268	4	-	-	X
- Turn	975	45000	283	2	3.5	-	X
- Cruise	975	45000	283	4	-	-	X
- Turn	975	45000	253	2	3.0	-	X
- Cruise	975	45000	253	4	-	-	X

(TABLE B-1) (Concluded)

HIGH ALTITUDE GROUND ATTACK MISSION

		ENDING CONDITIONS				MANEUVER CONSTRAINTS		
	SEGMENT DESCRIPTION	AIRSPEED (KTAS)	ALTITUDE (FT)	HEADING (DEG)	RANGE (NM)	LOAD FACTOR (G'S)	CLIMB ANG (DEG)	A/B OPERATION
	- Turn	975	45000	203	2	3.5	-	X
	- Cruise	975	45000	203	6	-	-	X
	- Turn	975	45000	293	3	3.0	-	X
	- Cruise	975	45000	293	3	-	-	X
	- Sustained Turn	550	45000	73	-	-	-	X
12.	Cruise	490	45000	073	31	-	-	
13.	Turn	490	45000	000	2	1.7	-	
14.	Rejoin	490	45000	000	2	-	-	
15.	Descent	490	35000	000	25	-	-15°	
16.	Descent	490	10000	000	25	-	-15°	
17.	Descent	425	1500	000	15	-	-15°	
18.	Overhead Landing =	2 Touch and Go's						

TABLE B-2

LOW ALTITUDE GROUND ATTACK MISSION

	SEGMENT DESCRIPTION	ENDING CONDITIONS AIRSPEED (KTAS)	ALTITUDE (FT)	HEADING (DEG)	RANGE (NM)	MANEUVER CONSTRAINTS LOAD FACTOR (G'S)	CLIMB ANG (DEG)	A/B OPERATION
1.	Takeoff	400	1500	170	-	2.0	-	X
2.	Climb	385	7000	170	5	2.0	-	
3.	Rejoin	385	7000	234	2	-	-	
4.	Cruise	385	7000	234	2.5	2.0	-	
5.	Turn-Descent	400	2000	246	7	3.0	-	
6.	Deceleration	360	2000	246	19.7	2.0	-	
7.	Turn	360	2000	287	13	2.0	-	
8.	Descent	580	600	287	5	3.0	-	
9.	Terrain Following[1]	580	150 AGL	287	43.6	Medium Ride	-	
10.	Turn	580	800	360	2	2.0	-	
11.	Terrain Following[2]	580	150 AGL	360	19.7	Medium Ride	-	
12.	Turn	580	1300	109	2	2.0	-	
13.	Terrain Following[3]	580	150 AGL	109	65	Medium Ride	-	
14.	Turn	580	2300	49	2	2.0	-	

(TABLE B-2) (Continued)

LOW ALTITUDE GROUND ATTACK MISSION

	SEGMENT DESCRIPTION	ENDING CONDITIONS AIRSPEED (KTAS)	ALTITUDE (FT)	HEADING (DEG)	RANGE (NM)	MANEUVER CONSTRAINTS LOAD FACTOR (G'S)	CLIMB ANG (DEG)	A/B OPERATION
15.	Terrain Following[4]	580	150 AGl	49	18	Medium Ride	-	
16.	Turn	580	500	230	8	2.0	-	
17.	Pop-up Pattern							
	(a) Ingress	500	500	230		3.0	-	
	(b) Pull-Up	500	1200	230	6	3.0	-	
	(c) Pull-Over	570	1200	180		5.0	-	
	(d) Dive	500	400	180		-	-10°	
	(e) Climb-Turn	370	4500	60	3.5	3.0	-	
	(f) Turn	390	3500	0	1.5	2.5	-	
	(g) Cruise	390	3500	0	3	1.2	-	
	(h) Turn	390	3500	270	1	2.0	-	
	(i) Turn	400	2500	180	1	2.0	-	
18.	10° Dive Pattern							
	(a) Ingress	450	2500	180		2.5	-	
	(b) Pull-Over	470	2500	180	3	3.0	-	

(TABLE B-2) (Continued)

LOW ALTITUDE GROUND ATTACK MISSION

SEGMENT DESCRIPTION	ENDING CONDITIONS AIRSPEED (KTAS)	ALTITUDE (FT)	HEADING (DEG)	RANGE (NM)	MANEUVER CONSTRAINTS LOAD FACTOR (G'S)	CLIMB ANG (DEG)	A/B OPERATION
(c) Dive	500	400	180		3.0	-10°	
(d) Recovery	570	1200	180		4.0	-	
(e) Climb-Turn	380	5200	60	3	3.0	-	
(f) Turn	390	3500	0	1	2.5	-	
(g) Cruise	390	3500	0	3	1.2	-	
(h) Turn	390	3500	270	1	2.0	-	
(i) Turn	400	2500	180	1	2.0	-	
19. 30° Toss Pattern							
(a) Ingress	450	500			2.5	-	
(b) Toss	500	3000	30	3	2.5	-	
(c) Recovery	500	3000			4.0	-	
(d) Climb-Turn	390	6000	60	3	3.0	-	
(e) Turn	380	8000	0	2.5	2.5	-	
(f) Cruise	390	8000	0	1.2	1.2	-	

(TABLE B-2) (Continued)

LOW ALTITUDE GROUND ATTACK MISSION

SEGMENT DESCRIPTION	ENDING CONDITIONS AIRSPEED (KTAS)	ALTITUDE (FT)	HEADING (DEG)	RANGE (NM)	MANEUVER CONSTRAINTS LOAD FACTOR (G'S)	CLIMB ANG (DEG)	A/B OPERATION
(g) Turn	390	8000	270	2.5	2.5	-	
(h) Turn	400	7000	180	2.5	2.5	-	
20. 30° Dive Pattern #1							
(a) *Ingress*	450	7000	180		3.5	-	
(b) Pull-Over	475	7000	180	6	4.0	-	
(c) Dive	500	1200	180		-	-30°	
(d) Recovery	570	2500	180		5.0	-	
(e) Climb-Turn	350	8200	60	3	3.0	-	
(f) Turn	370	8000	0	2	2.5	-	
(g) Cruise	390	8000	0	6	1.2	-	
(h) Turn	390	8000	270	1	2.5	-	
(i) Turn	400	7000	180	2	2.5	-	
21. 30° Dive Pattern #2							
(a) Ingress							
(b) Pull-Over	Same as in 30° Dive Pattern #1						

(TABLE B-2) (Continued)

LOW ALTITUDE GROUND ATTACK MISSION

SEGMENT DESCRIPTION	ENDING CONDITIONS AIRSPEED (KTAS)	ALTITUDE (FT)	HEADING (DEG)	RANGE (NM)	MANEUVER CONSTRAINTS LOAD FACTOR (G'S)	CLIMB ANG (DEG)	A/B OPERATION
(c) Dive							
(d) Recovery							
(e) Climb-Turn	370	6000	60	3	3.0	-	
(f) Turn	380	5000	0	2	2.5	-	
22. 20° Dive Pattern #1							
(a) Ingress	450	4000	180		2.5	-	
(b) Dive	500	200	180	4	-	-20°	
(c) Recovery	570	2500	180		4.0	-	
(d) Climb-Turn	360	6000	60	3	3.0	-	
(e) Turn	390	8000	0	2	2.5	-	
(f) Cruise	395	5000	0	4	1.2	-	
(g) Turn	395	5000	270	1	2.5	-	
(h) Turn	400	4000	180	1	2.5	-	
23. 20° Dive Pattern #2							
(a) Ingress							

(TABLE B-2) (Continued)

LOW ALTITUDE GROUND ATTACK MISSION

SEGMENT DESCRIPTION	ENDING CONDITIONS AIRSPEED (KTAS)	ALTITUDE (FT)	HEADING (DEG)	RANGE (NM)	MANEUVER CONSTRAINTS LOAD FACTOR (G'S)	CLIMB ANG (DEG)	A/B OPERATION
(b) Dive	Same as in 20° Dive Pattern #1						
(c) Recovery							
(d) Climb-Turn	380	8200	60	2.5	3.0	-	
(e) Turn	370	8000	0	2	2.5	-	
(f) Cruise	390	8000	0	6	1.2	-	
(g) Turn	390	8000	270	1	2.5	-	
(h) Turn	400	7000	180	1	2.5	-	
24. 30° Dive Pattern #1	(Repeat of #20)						
25. 30° Dive Pattern #2	(Repeat of #21)						
26. 20° Dive	500	1200	180	2	-	-20°	
27. Climb-Turn	360	6000	60	3	3.0	-	
28. turn	390	6000	0	3	3.0	-	
29. Decelerating Turn	265	5000	180	2	3.0	-	
30. Cruise	265	5000	180	9	2.0	-	
31. Turn	265	5000	0	2	3.0	-	

(TABLE B-2) (Concluded)

LOW ALTITUDE GROUND ATTACK MISSION

	SEGMENT DESCRIPTION	ENDING CONDITIONS AIRSPEED (KTAS)	ALTITUDE (FT)	HEADING (DEG)	RANGE (NM)	MANEUVER CONSTRAINTS LOAD FACTOR (G'S)	CLIMB ANG (DEG)	A/B OPERATION
32.	Turn	265	5000	124.5	2	2.0	-	
33.	Cruise	265	5000	124.5	13	2.0	-	

34. *Overhead Landing:* No Touch and Go's

Notes:
1. Terrain Pattern Penn 234
2. Terrain Pattern Path 14
3. Terrain Pattern Rughead
4. Terrain Pattern Shortdoll

TABLE B-3

DEFENSIVE AIR COMBAT MISSION

SEGMENT DESCRIPTION	ENDING CONDITIONS AIRSPEED (KTAS)	ALTITUDE (FT)	HEADING (DEG)	RANGE (NM)	MANEUVER CONSTRAINTS LOAD FACTOR (G'S)	CLIMB ANG (DEG)	A/B OPERATION
1. Cruise Out							
(a) Takeoff	350	5000	170	-	2		
(b) Climbing Turn	340	15000	085	7	1.8		
(c) Accelerating Turn	425	15000	170	12	2		
(d) Turn	425	15000	190	2	1.2		
(e) Rejoin	425	15000	190	3	-		
(200 Ft Final Separation)							
(f) Climb	460	20000	190	10	2		
(g) Cruise	460	20000	190	55	2		
(h) Turn	460	20000	270	4	1.5		
(i) Acceleration	560	20000	270	12	2		
2. Five "Average" Air Combat Engagements Selected From 92 engagements Simulated in Air Combat Model							

(TABLE B-3) (Concluded)

DEFENSIVE AIR COMBAT MISSION

SEGMENT DESCRIPTION	ENDING CONDITIONS AIRSPEED (KTAS)	ALTITUDE (FT)	HEADING (DEG)	RANGE (NM)	MANEUVER CONSTRAINTS LOAD FACTOR (G'S)	CLIMB ANG (DEG)	A/B OPERATION
3. Cruise Back							
(a) Cruise	460	2000	010	25	2		
(b) Descent	380	7000	010	25	2		
(c) Descending Turn	375	6500	350	25	2		
(d) Descent	350	1500	350	10	2		
(e) Overhead Landing	No Touch and Goes						

TABLE B-4

INSTRUMENT PROFICIENCY/WITH REFUELING

	SEGMENT DESCRIPTION	ENDING CONDITIONS AIRSPEED (KTAS)	ALTITUDE (FT)	HEADING (DEG)	RANGE (NM)	MANEUVER CONSTRAINTS LOAD FACTOR (G'S)	CLIMB ANG (DEG)	A/B OPERATION
1.	Takeoff	350	5000	170°	-	2.0	-	X
2.	Climb	340	15000	85°	7	1.8	-	
3.	Cruise	370	15000	85°	20	1.2	-	
4.	Climb	350	31000	93°	5	2.5	-	
5.	Acceleration	540	31000	93°	40	1.5	-	
6.	Acceleration	395	31000	93°	15	1.5	-	
7.	Rejoin With Tanker	375	31000	112°	8	-	-	
8-11.	Refueling Taps (4)						1500 Lb Fuel Transfer	
12.	Descent	520	30000	112°	9	1.2	-	
13.	Turn	520	30000	328°	5	1.3	-	
14.	Climb	430	40000	328°	12	5.0	-	
15.	Acceleration	520	40000	328°	23	1.2	-	
16.	Cruise	520	40000	328°	35	1.2	-	
17.	Turn	520	40000	285°	5	1.3	-	
18.	Cruise	520	40000	285°	40	1.1	-	

(TABLE B-4) (Continued)

INSTRUMENT PROFICIENCY/WITH REFUELING

	SEGMENT DESCRIPTION	ENDING CONDITIONS AIRSPEED (KTAS)	ALTITUDE (FT)	HEADING (DEG)	RANGE (NM)	MANEUVER CONSTRAINTS LOAD FACTOR (G'S)	CLIMB ANG (DEG)	A/B OPERATION
19.	Turn	520	40000	323°	5	1.3	-	
20.	Cruise	520	40000	323°	61	1.1	-	
21.	Turn	520	40000	310°	3	1.3	-	
22.	Descent	420	20000	310°	32	1.8	-	
23.	Descent	390	10000	310°	20	1.2	-	
24.	Descent	350	5000	310°	12	1.2	-	
25.	Descent	320	4000	270°	6	1.5	-	
26.	Turn	290	4000	0°	5	1.5	-	
27.	Turn	250	3500	70°	3	1.5	-	
28.	Descent	265	1500	70°	4	1.6	-	
29.	Climb - Turn	350	5000	165°	5	1.5	-	
30.	Climb	300	31000	165°	10	1.5	-	
31.	Acceleration	360	31000	165°	20	1.1	-	
32.	Turn	370	31000	179°	5	1.3	-	
33.	Cruise	370	31000	179°	30	1.1	-	

(TABLE B-4) (Concluded)

INSTRUMENT PROFICIENCY/WITH REFUELING

		ENDING CONDITIONS				MANEUVER CONSTRAINTS		
	SEGMENT DESCRIPTION	AIRSPEED (KTAS)	ALTITUDE (FT)	HEADING (DEG)	RANGE (NM)	LOAD FACTOR (G'S)	CLIMB ANG (DEG)	A/B OPERATION
34.	Descent	340	15000	179°	30	1.3	-	
35.	Descent - Turn	320	10000	300°	4	1.3	-	
36.	Turn	300	9000	190°	3	1.3	-	
37.	Descent	320	1500	190°	5	1.5	-	
38.	Climb	290	5000	190°	3	2.0	-	
39.	Cruise	300	5000	190°	6	1.1	-	
40.	Landing Pattern - 5 Touch and Goes							

TABLE B-5

INSTRUMENT PROFICIENCY/WITHOUT REFUELING

	SEGMENT DESCRIPTION	ENDING CONDITIONS AIRSPEED (KTAS)	ALTITUDE (FT)	HEADING (DEG)	RANGE (NM)	MANEUVER CONSTRAINTS LOAD FACTOR (G'S)	CLIMB ANG (DEG)	A/B OPERATION
1.	Takeoff	350	5000	170°	-	2.0	-	X
2.	Climb	340	15000	85°	7	1.8	-	
3.	Cruise	370	15000	85°	20	1.2	-	
4.	Climb	350	31000	93°	5	2.5	-	
5.	Acceleration	540	31000	93°	40	1.5	-	
6.	Cruise	540	31000	93°	15	1.5	-	
7.	Turn	540	31000	96°	6	1.3	-	
8.	Climb	480	40000	96°	12	5.0	-	
9.	Acceleration	490	40000	96°	5	1.3	-	
10.	Accelerating Turn	520	40000	304°	27	1.2	-	
11.	Turn	520	40000	285°	5	1.3	-	
12.	Cruise	520	40000	285°	40	1.1	-	
13.	Turn	520	40000	323°	5	1.3	-	
14.	Cruise	520	40000	323°	61	1.1	-	
15.	Turn	520	40000	310°	3	1.3	-	

(TABLE B-5) (Continued)

INSTRUMENT PROFICIENCY/WITHOUT REFUELING

	SEGMENT DESCRIPTION	ENDING CONDITIONS AIRSPEED (KTAS)	ALTITUDE (FT)	HEADING (DEG)	RANGE (NM)	MANEUVER CONSTRAINTS LOAD FACTOR (G'S)	CLIMB ANG (DEG)	A/B OPERATION
16.	Descent	420	20000	310°	32	1.8	-	
17.	Descent	390	10000	310°	20	1.2	-	
18.	Descent	350	5000	310°	12	1.2	-	
19.	Descent	320	4000	270°	6	1.5	-	
20.	Turn	290	4000	0°	5	1.5	-	
21.	Turn	250	3500	70°	3	1.5	-	
22.	Descent	265	1500	70°	4	1.6	-	
23.	Climb - Turn	350	5000	165°	5	1.4	-	
24.	Climb	300	31000	165°	10	1.5	-	
25.	Acceleration	360	31000	165°	20	1.1	-	
26.	Turn	370	31000	179°	5	1.3	-	
27.	Cruise	370	31000	179°	30	1.1	-	
28.	Descent	340	15000	179°	30	1.3	-	
29.	Descent - Turn	320	10000	300°	4	1.3	-	

(TABLE B-5) (Concluded)

INSTRUMENT PROFICIENCY/WITHOUT REFUELING

	SEGMENT DESCRIPTION	ENDING CONDITIONS AIRSPEED (KTAS)	ALTITUDE (FT)	HEADING (DEG)	RANGE (NM)	MANEUVER CONSTRAINTS LOAD FACTOR (G'S)	CLIMB ANG (DEG)	A/B OPERATION
30.	Turn	300	9000	190°	3	1.3	-	
31.	Descent	320	1500	190°	5	1.5	-	
32.	Climb	290	5000	190°	3	2.0	-	
33.	Cruise	300	5000	190°	6	1.1	-	
34.	Landing Pattern - 5 Touch and Goes							

TABLE B-6

LUKE TRANSITIONAL TRAINING MISSION - BASIC

	SEGMENT DESCRIPTION	ENDING CONDITIONS AIRSPEED (KTAS)	ALTITUDE (FT)	HEADING (DEG)	RANGE (NM)	MANEUVER CONSTRAINTS LOAD FACTOR (G'S)	CLIMB ANG (DEG)	A/B OPERATION
1.	Takeoff	350	5000	070	-	2		
2.	Rejoin (200 Ft Final Separation)	370	5000	070	1	-		
3.	Climb	430	16000	070	10.5	1.15		
4.	Cruise	430	16000	070	14	1.15		
5.	Climb	460	23000	070	6.5	1.15		
6.	Cruise	460	23000	070	16	1.15		
7.	Descent	400	15000	070	12	1.15		
8.	Turn	400	15000	115	1	2		
9.	Turn	400	15000	070	1	2		
10.	Cruise	400	15000	070	14	2		
11.	Turn	370	15000	160	1.8	2		
12.	Turn	370	15000	070	1.8	2		
13.	Turn	370	15000	340	1.8	2		
14.	Turn	370	15000	070	1.8	2		

(TABLE B-6) (Continued)

LUKE TRANSITIONAL TRAINING MISSION - BASIC

		Ending Conditions				Maneuver Constraints		
	SEGMENT DESCRIPTION	AIRSPEED (KTAS)	ALTITUDE (FT)	HEADING (DEG)	RANGE (NM)	LOAD FACTOR (G'S)	CLIMB ANG (DEG)	A/B OPERATION
15.	Deceleration	310	15000	070	14	2		
16.	Turn	310	15000	160	1.3	2		
17	Turn	310	15000	070	1.3	2		
[illegible]	Turn	310	15000	340	1.3	2		
1[illegible]	Turn	310	15000	070	1.3	2		
20.	Turn	310	15000	090	10	2		
21.	Deceleration	200	15000	090	1	2		
22.	Descent	170	10000	090	15.7	3		
23.	Acceleration	350	10000	090	2.5	2		
24.	Climbing Turn	310	15000	270	4.5	3		
25.	Deceleration	200	15000	270	4.5	2		
26.	Descent	170	10000	270	15	3		
27.	Acceleration	350	10000	270	2.5	2		
28.	Climbing Turn	310	15000	090	4.5	3		
29.	Deceleration	200	15000	090	1	2		

(TABLE B-6) (Continued)

LUKE TRANSITIONAL TRAINING MISSION - BASIC

		ENDING CONDITIONS				MANEUVER CONSTRAINTS		
	SEGMENT DESCRIPTION	AIRSPEED (KTAS)	ALTITUDE (FT)	HEADING (DEG)	RANGE (NM)	LOAD FACTOR (G'S)	CLIMB ANG (DEG)	A/B OPERATION
30.	Descent	170	10000	090	15	2		
31.	Acceleration	400	10000	090	2.5	2		
32.	Climb	310	15000	270	4.5	3		
33.	Deceleration	200	15000	270	1	2		
34.	Descent	170	10000	270	15	3		
35.	Acceleration	400	10000	270	2	2		
36.	Climb	250	15000	270	.5	4	+60	X
37.	Accelerating Turn	540	15000	000	10	2		
38.	Descent	530	10000	000	.8	6	-45	
39.	Decelerating Turn	410	10000	180	14	6		
40.	Climb	430	15000	180	1.5	4	+60	X
41.	Cruise	430	15000	180	14	4		
42.	Descending Turn	560	10000	250	1.5	4	-30	
43.	Cruise	560	10000	250	14	4		
44.	Pitchback	300	15000	070		5		

(TABLE B-6) (Concluded)

LUKE TRANSITIONAL TRAINING MISSION - BASIC

		ENDING CONDITIONS				MANEUVER CONSTRAINTS		
	SEGMENT DESCRIPTION	AIRSPEED (KTAS)	ALTITUDE (FT)	HEADING (DEG)	RANGE (NM)	LOAD FACTOR (G'S)	CLIMB ANG (DEG)	A/B OPERATION
45.	Split - S	300	10000	250		5		X
46.	Climb	460	23000	250	12	1.15		
47.	Climb	460	23000	250	17	1.15		
48.	Descent	350	3000	250	37.6	1.15		
49.	Descent	350	2200	330	1.5	2		
50.	Overhead Landing 6 Touch and Goes							

TABLE B-7

LUKE TRANSITIONAL TRAINING - ADVANCED

	SEGMENT DESCRIPTION	ENDING CONDITIONS AIRSPEED (KTAS)	ALTITUDE (FT)	HEADING (DEG)	RANGE (NM)	MANEUVER CONSTRAINTS LOAD FACTOR (G'S)	CLIMB ANG (DEG)	A/B OPERATION
1.	Takeoff	350	1500	70°	-	2.0	-	
2.	Climb	370	5000	70°	6	1.15	-	
3.	Rejoin	370	5000	70°	1	-		
4.	Climb	430	15000	70°	8.5	1.15	-	
5.	Cruise	460	15000	70°	14	1.15	-	
6.	Climb	460	23000	70°	5	1.15	-	
7.	Cruise	460	15000	70°	16	1.15	-	
8.	Descent - Turn	400	15000	90°	12	1.15	-	
9.	Cruise	400	15000	90°	10	2.0	-	
10.	Turn	400	15000	0°	3.3	1.5	-	
11.	Cruise	400	15000	0°	10	2.0	-	
12.	Turn	400	15000	270°	3.3	1.5	-	
13.	Cruise	400	15000	270°	1	1.15	-	
14.	Turn	400	15000	180°	6	4.0	-	
15.	Turn	400	15000	0°	4.5	2.0	-	

(TABLE B-7) (Continued)

LUKE TRANSITIONAL TRAINING - ADVANCED

	SEGMENT DESCRIPTION	ENDING CONDITIONS AIRSPEED (KTAS)	ALTITUDE (FT)	HEADING (DEG)	RANGE (NM)	MANEUVER CONSTRAINTS LOAD FACTOR (G'S)	CLIMB ANG (DEG)	A/B OPERATION
16.	Rejoin	400	15000	270°	9.2	-	-	
17.	Cruise	400	15000	270°	33	2.0	-	
18.	Turn	400	15000	0°	6	4.0	-	
19.	Turn	400	15000	180°	4.2	2.0	-	
20.	Rejoin	400	15000	180°	6.3	-	-	
21.	Turn - Climb	450	20000	135°	9.2	1.15	-	
22.	Turn	450	20000	225°	5	4.0	-	
23.	Rejoin	400	15000	180°	3.5	-	-	
24.	Turn	400	15000	135°	2	2.0	-	
25.	Cruise	400	15000	135°	3.3	2.0	-	
26.	Descent	400	10000	45°	1.4	4.0	-	
27.	Turn	400	10000	180°	2	3.0	-	
28.	Rejoin	400	15000	135°	10	-	-	
29.	Turn	400	15000	90°	2	2.0	-	
30.	Cruise	400	15000	90°	3.3	2.0	-	

(TABLE B-7) (Continued)

LUKE TRANSITIONAL TRAINING - ADVANCED

		ENDING CONDITIONS				MANEUVER CONSTRAINTS		
	SEGMENT DESCRIPTION	AIRSPEED (KTAS)	ALTITUDE (FT)	HEADING (DEG)	RANGE (NM)	LOAD FACTOR (G'S)	CLIMB ANG (DEG)	A/B OPERATION
31.	Turn	400	15000	0°	3.3	1.5	-	
32.	Descent - Turn	400	10000	180°	9.4	1.5	-	
33.	Cruise	400	10000	180°	3.3	2.0	-	
34.	Turn	400	10000	90°	3.3	2.0	-	
35.	Pitchback	380	15000	270°	-	5.0	-	X
36.	Acceleration	680	15000	270°	5	2.0	-	
37.	Pitchback	520	20000	90°	-	6.0	-	X
38.	Turn	520	20000	135°	0.5	6.0	-	
39.	Turn	520	20000	90°	0.5	6.0	-	
40.	Deceleration	440	20000	90°	1	2.0	-	
41.	Turn	440	20000	45°	0.4	6.0	-	
42.	Turn	440	20000	90°	0.4	6.0	-	
43.	Deceleration	350	15000	90°	5	2.0	-	
44.	Split "S"	500	15000	270°	-	6.0	-	X
45.	Turn	500	15000	210°	0.7	6.0	-	

(TABLE B-7) (Continued)

LUKE TRANSITIONAL TRAINING - ADVANCED

		ENDING CONDITIONS				MANEUVER CONSTRAINTS		
	SEGMENT DESCRIPTION	AIRSPEED (KTAS)	ALTITUDE (FT)	HEADING (DEG)	RANGE (NM)	LOAD FACTOR (G'S)	CLIMB ANG (DEG)	A/B OPERATION
46.	Turn	350	15000	270°	0.7	6.0	-	X
47.	Split "S"	450	10000	90°	-	6.0	-	X
48.	Turn	450	10000	45°	0.4	6.0	-	X
49.	Turn	450	10000	90°	0.4	6.0	-	
50.	Turn	400	10000	270°	3	1.15	-	
51.	Climb	460	23000	270°	3.3	1.15	-	
52.	Turn - Cruise	460	23000	260°	50	1.2	-	
53.	Descent	420	17000	226°	8	1.15	-	
54.	Turn	420	17000	136°	13	1.15	-	
55.	Descent	300	2500	240°	29	1.2	-	
56.	Turn	300	2500	330°	2	2.0	-	
57.	Deceleration	200	2500	330°	9	1.5	-	
58.	Decel - Descent	170	200	330°	7	1.15	-	
59.	Acceleration	250	200	330°	2	1.15	-	
60.	Climb	300	5000	340°	5	4.0	-	

(TABLE B-7) (Concluded)

LUKE TRANSITIONAL TRAINING - ADVANCED

	SEGMENT DESCRIPTION	ENDING CONDITIONS AIRSPEED (KTAS)	ALTITUDE (FT)	HEADING (DEG)	RANGE (NM)	MANEUVER CONSTRAINTS LOAD FACTOR (G'S)	CLIMB ANG (DEG)	A/B OPERATION
61.	Cruise	300	5000	340°	9	1.2	-	
62.	Turn	300	5000	250°	3.6	1.2	-	
63.	Turn	300	5000	60°	4.6	1.2	-	
64.	Turn - Climb	300	5600	330°	3.6	1.2	-	
65.	Descent	170	200	330°	15	1.2	-	
66.	Acceleration	250	200	330°	2	2.0	-	
67.	Climb	300	5000	340°	3.6	1.2	-	
68.	Turn	300	5000	250°	3.6	1.2	-	
69.	Turn	300	5000	150°	24.4	1.1	-	
70.	Overhead Landing - 2 Touch and Goes							

TABLE B-8

FUNCTIONAL CHECK FLIGHT

	SEGMENT DESCRIPTION	ENDING CONDITIONS AIRSPEED (KTAS)	ALTITUDE (FT)	HEADING (DEG)	RANGE (NM)	MANEUVER CONSTRAINTS LOAD FACTOR (G'S)	CLIMB ANG (DEG)	A/B OPERATION
1.	Takeoff	350	1500	170	-	2		X
2.	Climb	350	15000	167	5	3		
3.	Climb	400	40000	167	45	2		
4.	Accel	487	40000	167	36	2		
5.	Turn	487	40000	253	10	1.7		
6.	Acceleration	917	40000	253	20	3		X
7.	Supersonic Dash	917	40000	253	20	3		X
8.	Supersonic Turn	917	40000	073	10	3		X
9.	Supersonic Dash	917	40000	073	30	3		X
10.	Supersonic Descent	917	35000	073	5	2		X
11.	Deceleration - Turn	580	35000	253	10	2.5		X
12.	Throttle Chop	300	35000	253	1	3		
13.	Throttle Snap (Idle To Max A/B)	900	35000	253	1	3		X
14.	Cruise	580	35000	253	35	3		

(TABLE B-8) (Continued)

FUNCTIONAL CHECK FLIGHT

		ENDING CONDITIONS				MANEUVER CONSTRAINTS		
	SEGMENT DESCRIPTION	AIRSPEED (KTAS)	ALTITUDE (FT)	HEADING (DEG)	RANGE (NM)	LOAD FACTOR (G'S)	CLIMB ANG (DEG)	A/B OPERATION
15.	Turn	580	35000	073	10	2.5		
16.	Cruise	580	35000	073	30	3		
17.	Descent	580	30000	073	5	2.5		
18.	Deceleration Turn	470	30000	253	10	2.5		
19.	Throttle Chop	300	30000	253	.5	2.5		
20.	Throttle Snap (Idle To Max A/B)	900	30000	253	.9	2.5		
21.	A/B Light (Int To Max A/B)	900	30000	253	1.0	3		X
22.	Throttle Chop	300	30000	253	1.0	3		
23.	Cruise	470	30000	253	30	3		
24.	Turn	470	30000	073	10	2.5		
25.	Cruise	470	30000	073	30	3		
26.	Descent	470	25000	073	10	2.5		
27.	Deceleration Turn	450	25000	253	10	2.5		

(TABLE B-8) (Concluded)

FUNCTIONAL CHECK FLIGHT

	SEGMENT DESCRIPTION	ENDING CONDITIONS AIRSPEED (KTAS)	ALTITUDE (FT)	HEADING (DEG)	RANGE (NM)	MANEUVER CONSTRAINTS LOAD FACTOR (G'S)	CLIMB ANG (DEG)	A/B OPERATION
28.	Throttle Chop	300	25000	253	1	3		
29.	Throttle Snap	900	25000	253	1	3		X
30.	Turn Off A/B	900	25000	253	1	3		
31.	Throttle Chop (Int To Idle)	300	25000	253	1	3		X
32.	Cruise	450	25000	253	30	2.5		
33.	Turn	450	25000	073	10	2.5		
34.	Cruise	450	25000	073	30	3		
35.	Descending Turn	450	24000	001	2	1.7		
36.	Cruise	450	24000	000	45	3		
37.	Descent	425	1500	000	20	2		
38.	Overhead Landing	No Touch and Goes						

TABLE B-9

MISSION: FERRY/CROSS COUNTRY MISSION

		ENDING CONDITIONS				MANEUVER CONSTRAINTS		
	SEGMENT DESCRIPTION	AIRSPEED (KTAS)	ALTITUDE (FT)	HEADING (DEG)	RANGE (NM)	LOAD FACTOR (G'S)	CLIMB ANG (DEG)	A/B OPERATION
1.	Takeoff	350	1500	170°	-	2.0	-	X
2.	Accelerating Turn	460	1500	70°	20	3.0	-	
3.	Climb	460	35000	70°	25	3.0	-	
4.	Cruise	460	35000	70°	320	3.0	-	
5.	Climb	460	40000	70°	20	2.0	-	
6.	Accel	487	40000	70°	5	2.5	-	
7.	Cruise	487	40000	70°	585	2.0	-	
8.	Descent	425	10000	70°	100	1.5	-	
9.	Descent	400	2000	70°	50	1.5	-	
10.	Straight In Landing:	No Touch and Go's						

*U.S.Government Printing Office: 1982 — 559-003/2019